Chapter 9
Significance of Information Technologies

Contents

Highlights

IT and the Economy

- **The Internet and the World Wide Web are expanding rapidly, domestically and internationally.** The number of Internet hosts (computers connected to the Web) has grown from about 1 million in 1992 to 60 million in mid-1999. The United States is second to Finland in the number of Internet hosts per capita.
- **The information technology (IT) industry has contributed substantially to U.S. economic performance**. Growth in the IT industry contributed an estimated 29 percent of growth in real Gross Domestic Income in 1998. Declining prices in IT-producing industries contributed to reduced inflation in the overall economy.
- **Internet-based electronic commerce is growing rapidly and changing the impact of IT on the economy**. Private market research firms estimated that the value of transactions conducted over the Internet will reach $1 trillion by 2003 (up from $40–100 billion in 1998).
- **Electronic commerce is encouraging international efforts to develop more consistent and predictable legal regimes.** National and subnational laws and regulation come into conflict on the Internet in intellectual property, privacy, content, and other areas.
- **An increase in income inequity has coincided with the computerization of the workplace.** IT appears to have increased the demand for high-skill jobs in absolute terms as well as relative to low-skill jobs.
- **There has been a strong growth in the demand for workers with IT skills.** The Bureau of Labor Statistics projects that more than 1.3 million new computer scientists, computer engineers, systems analysts, and computer programmers will be needed between 1996 and 2006.

IT, Education, and Knowledge Creation

- **Schools are rapidly connecting to the Internet.** By 1998, 89 percent of public schools were connected to the Internet (up from 35 percent in 1994). In 1998, 51 percent of instructional rooms in public schools were connected to the Internet—up from 3 percent in 1994 and 27 percent in 1997.
- **Colleges are increasingly using IT in instruction**. The percentage of college courses using e-mail, Internet resources, class Web pages, and other forms of information technology in instruction increased rapidly between 1994 and 1998.
- **The effectiveness of information technology in education is still unclear.** Many studies show that information technology has positive effects on learning, but its cost-effectiveness relative to other investments in education is less clear.
- **Distance education using information technology is expanding rapidly and opens educational opportunities for nontraditional students.** It also raises new issues regarding ownership of intellectual property rights in instructional material and concerns about the future of traditional education.
- **Electronic scholarly communication is expanding rapidly.** The number of electronic journals doubled between 1996 and 1997. Preprint servers have proven to be very efficient modes of scholarly communication and have become major modes of communications in some fields.
- **The amount of information on the World Wide Web is approaching the amount of text in the largest libraries.** The World Wide Web was estimated to contain 6 trillion bytes of text in February 1999—equivalent to 6 million books. About 6 percent of Web servers are based at universities, colleges, or research laboratories.
- **IT is increasingly important in research**. In addition to the traditional use of computing in the physical sciences and engineering, information technologies are having increasing impact in biology (especially genomics) and are providing new tools for research collaboration.

IT and the Citizen

- **Home access to personal computers and the Internet is increasing rapidly.** The percentage of U.S. households owning a home computer increased from 24 percent in 1994 to 42 percent in 1998. The percentage of households with access to the Internet increased from 2 percent in 1994 to 26 percent in 1998.
- **There are differences in home adoption of IT by income level, race/ethnicity, and geographic location.** People who are more affluent, more highly educated, and in higher-status occupations are more likely to have home personal computers and Internet access. Even after controlling for differences in income, blacks lag whites in ownership of home computers and in linking to the Internet.
- **Home use of the Internet is primarily for e-mail and World Wide Web activity.** Health and medicine are the most popular Internet subjects.
- **Governments around the world are using the Internet and the World Wide Web to communicate with constituencies.** Most countries have Web sites for some of their agencies. Almost 40 had Web sites for 70 percent or more of their top-level agencies.

Introduction

Chapter Overview

The revolution in information technology (IT) has been likened to the industrial revolution in terms of its potential scope and impact on society (Alberts and Papp 1997; Castells 1996; Freeman, Soete, and Efendioglu 1995; Kranzberg 1989). Few other modern advances in technology have had the capacity to affect so fundamentally the way people work, live, learn, play, communicate, and govern themselves. As IT extends human capabilities and takes over other functions previously performed by humans, it can even affect what it means to be human.

It is far from clear what the total effects of IT on society will be. As Vannevar Bush (1945) noted more than 50 years ago, "The world has arrived at an age of cheap complex devices of great reliability; and something is bound to come of it." The question is, What has become of it? As with automobiles and television earlier in the 20th century, information technologies can be expected to have diverse and far reaching effects on society—some good, some bad, and many unanticipated.

The IT revolution raises many policy issues: How will IT affect the development and safety of children and the privacy of adults? How will IT affect the distribution of knowledge, wealth, and power among different groups in the United States and around the world? Will there be a "digital divide" between IT-rich and IT-poor groups that increases current inequalities? How will IT affect national sovereignty and international law? How will IT affect education and the future of libraries, universities, and scholarly communication? What measures are needed to make electronic commerce markets operate efficiently and fairly? Which issues can best be handled adequately in the private sector, and which require the involvement of the public sector? Although many of these questions are beginning to come into focus, data and research to answer these questions are lagging the changes that are occurring.

The information revolution is not new. The United States began moving toward an information-based economy in the 1960s, as information intensive services began to grow. At that time, computers were used mostly in the research and development (R&D) community and in the offices of large companies and agencies. In the past 20 years, however, IT has become increasingly pervasive in society. It has spread to the point that nearly everyone uses some form of IT every day. It has become common in schools, libraries, homes, offices, and shops. Corner grocery stores use IT for sales and electronic transactions; automobile repair shops use IT to diagnose failures and search for parts. In the past few years, the Internet and the World Wide Web in particular have contributed to the rapid expansion of IT. Innovations in IT now directly affect nearly everyone—not just the few in computer-intensive jobs.

As the market for IT has expanded, private investment in new technologies and manufacturing has increased—which in turn has led to new, better, and cheaper technologies. Costs have come down dramatically, and many new applications have been developed. Many of these advances provide return benefits to the science and engineering enterprise. For example, more powerful work stations, improved networking, and better databases all aid in research.

A discussion of IT in a collection of science and engineering indicators is important for two reasons. First, IT constitutes an important part of science and engineering's effect on society and the economy. It embodies advances in numerous fields, including computer science, computer engineering, electrical engineering, material science, mathematics, and physics. IT illustrates the effects of federal and private investment in R&D. Much IT has been developed by and for the R&D community, and the R&D community is an early user of many information technologies. Many of the effects of IT, such as the use of e-mail for communication or the World Wide Web for publication, take place first in the R&D community.

Second, IT is a major force affecting the U.S. and global science and engineering system. IT producers employ scientists and engineers, implement the results of academic research, and conduct significant amounts of applied research and development. IT affects the pipeline for science and engineering through its effects on the demand for people with technical skills and through its use in education at all levels. IT also affects the conduct of R&D in all disciplines. For example, the physical sciences make extensive use of computer modeling and simulation, and many aspects of biology (notably genomics) have become more information intensive. Advances in networking, meanwhile, facilitate the global nature of research collaboration.

This chapter provides an overview of the significance of IT for society and the economy; it focuses especially on the effects of IT on education and research. A complete discussion of the impact of information technology on society and the economy, however, is beyond the scope of this (or perhaps any) chapter. Other federal agencies and other organizations are addressing some areas. This chapter provides references and Web citations to direct the reader to more detailed and frequently updated information.

IT Data and Measurement

One major difficulty in analyzing the effect of IT on society is the difficulty in obtaining reliable national and internationally comparable data (CSTB 1998). There is little reliable, accepted, long-term data on either the diffusion of IT or its effects on society. The rate of technological change since the early 1980s has often outpaced our ability to define what we want to know and what data ought to be collected. Metrics are confounded by the changing nature of IT as a concept and the interactive effects of so many social variables—including age, ethnicity, income, learning processes, individual attitudes, organizational structures, culture, and management styles. In many cases, the effects of IT depend largely on how it is used. Positive effects often depend on appropriate organizational structures and managerial style, as well as the adequacy of training and the attitudes of individuals using IT.

Quantitative indicators of IT diffusion are relatively abundant but not standardized. Much of the available data is in the form of quickly developed, easily obtained information rather than long-term studies. Studies in many areas of interest often are not regularly repeated with the same methods. This lack of comparable data partly reflects the complexity and dynamism of IT: The most interesting things to measure change rapidly.

Indicators of the effects of IT—as opposed to the use of IT—on individuals, institutions, and markets are especially difficult to establish. This difficulty inhibits our ability to draw any definitive conclusions about the impacts of IT on society. Experts have had difficulty measuring productivity in service industries, in education, and in research and development. Consequently, determining the effects of IT on productivity in these areas is even more difficult. Moreover, IT often has effects in conflicting directions. There is evidence, for example, that IT can both increase and decrease productivity and contribute to both lowering and upgrading of skills in the labor force. Computer-aided instruction may enhance some forms of student learning, but extensive use of some computing environments may impede other aspects of child development.

This chapter attempts to compile relevant existing data and indicators; it also identifies the limitations of existing data and suggests how improvements to the data would be helpful. Data and measurement issues are identified throughout this chapter and are further discussed in the conclusion.

Information Technologies

Information technology, as defined in this chapter, reflects the combination of three key technologies: digital computing, data storage, and the ability to transmit digital signals through telecommunications networks. The foundation of modern information technologies and products is the ability to represent text, data, sound, and visual information digitally. By integrating computing and telecommunications equipment, IT offers the ability to access stored (or real-time) information and perform an extraordinary variety of tasks.

IT is not a single technology; it is a system of technologies in combination. There are literally hundreds of commercial products—ranging from telephones to supercomputers—that can be used singly or, increasingly, in various combinations in an information processing system. The different functions of many of these products contribute to a sense of fuzziness about IT's technological boundaries.

One approach is to group IT into four technological elements: human interface devices, communication links (including networks), information processing hardware and software, and storage media. (See figure 9-1.) There are substantial overlaps among the categories. For example, most human interface devices also have some information processing and storage capabilities.

The rapid social and economic diffusion of IT since 1980 has been stimulated by rapid changes in computing power, applications, telecommunications, and networks, as well as concurrent reductions in the cost of technology and, in some cases, improvements in ease of use. The most dramatic manifestations are enormous improvements in performance and reductions in cost of integrated circuits brought about by rapid miniaturization. (See sidebar, "Moore's Law.") Similar but less dramatic improvements in cost and performance have occurred in disk drives and other computer hardware.

In addition, new capabilities are being added to chips. For example, microelectromechanical systems such as sensors and actuators and digital signal processors are being put on chips, enabling cost reductions in these technologies and extending information technologies into new types of devices.

Another key development in IT is the growing connectivity of computers and information. Computers are increasingly connected in networks, including local area networks (LANs) and wide area networks (WANs). Many early commercial computer networks, such as those used by automated teller machines (ATMs) and airline reservation systems, used proprietary systems that required specialized software or hardware (or both). Increasingly, organizations are using open-standard, Internet-based systems for networks. Almost three-fourths of the personal computers in the United States are networked (WITSA 1999, 55). Worldwide, there were

Figure 9-1.
Technological components of an information processing system

Human interface devices	Communication links	Information processing	Storage media
• Computers • Telephones • Scanners • TVs • Displays • Printers • Digital cameras • Automated teller machines • Personal digital assistants	• Internet • Intranets • LANs • Telephone lines • Routing and switching • Coaxial cable • Fiber-optic lines • Satellite • Cellular	• Computer hardware - servers - work stations - PCs • Software - systems software - business and home applications - information searching and filtering	• Hard drives • Floppy disks • Optical disks • Magnetic tape • Memory chips and cards

Science & Engineering Indicators – 2000

Moore's Law

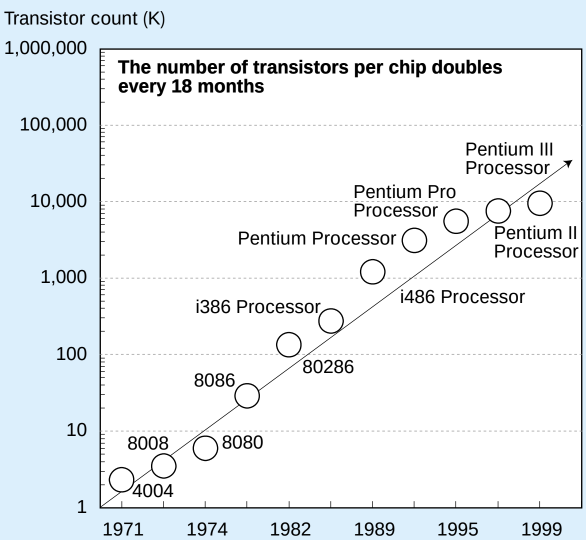
The number of transistors on a chip has doubled approximately every 12–18 months for the past 30 years—a trend referred to as Moore's Law. (See figure 9-2.) This trend is named for Gordon Moore of Intel, who first observed it. As Moore (1999) noted:

> I first observed the "doubling of transistor density on a manufactured die every year" in 1965, just four years after the first planar integrated circuit was discovered. The press called this "Moore's Law" and the name has stuck. To be honest, I did not expect this law to still be true some 30 years later, but I am now confident that it will be true for another 20 years.

Performance has increased along with the number of transistors per chips, while the cost of chips has remained fairly stable. These factors have driven enormous improvements in the performance/cost ratio. (See figure 9-3.)

The complexity and cost of developing new chips and new semiconductor manufacturing equipment also have increased. As a result, the industry has been driven toward greater economies of scale and industry-wide collaboration. Moore's Law—which began as the observation of an individual in a single company—has become a self-fulfilling prediction that drives industry-wide planning. Since 1992, the U.S. Semiconductor Industry Association (SIA) has developed a National Technology Roadmap for Semiconductors, which charts the steps the industry must take to maintain its rate of improvement. In 1998, this effort evolved into the International Technology Roadmap for Semiconductors, with participation by the Japanese, European, and South Korean semiconductor industries. The 1998 update projects the number of transistors per chip increasing to 3.6 billion in 2014 (SIA 1998).

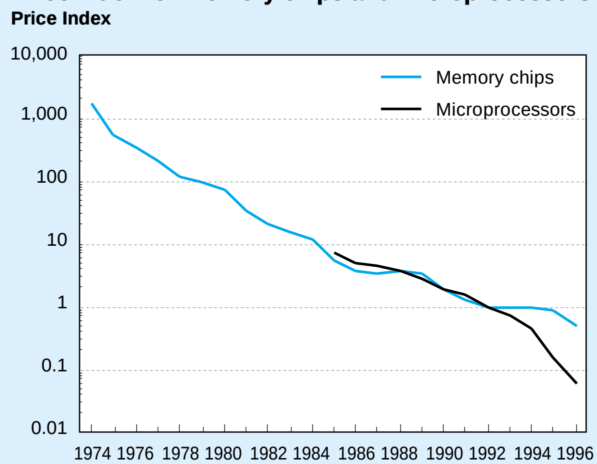
Figure 9-2.
Moore's Law



SOURCE: Intel. Available from <<http://www.intel.com/pressroom/kits/processors/quickref.htm>>.

See appendix table 9-1. *Science & Engineering Indicators – 2000*

Figure 9-3.
Price index for memory chips and microprocessors



NOTE: 1992 = 100 (Log scale)

SOURCE: Grimm, B.T. "Price Indexes for Selected Semiconductors, 1974–96." *Survey of Current Business* (February 1998). Available from <<http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPA/1998/0298od.pdf>>.

Science & Engineering Indicators – 2000

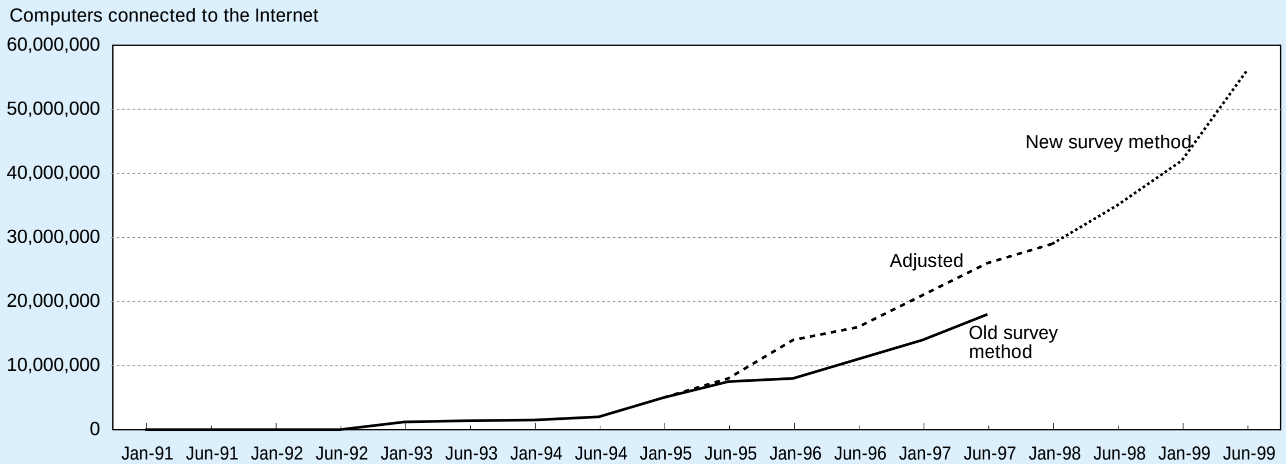
more than 56 million Internet hosts—computers connected to the Internet—in July 1999, up from about 30 million at the beginning of 1998. (See figure 9-4 and appendix table 9-2.)

Information Technology Over the Past 50 Years

IT and the National Science Foundation (NSF) have come of age together. In this year that marks the 50th anniversary of NSF, few areas demonstrate as vividly as IT the progress that has been made in science and engineering in the past half-century.

In 1945, the same year that Vannevar Bush outlined his ideas for what became the National Science Foundation in *Science—the Endless Frontier*, he also wrote an article in the *Atlantic Monthly* that described his vision for capturing and accessing information. (See sidebar, "Excerpts from 'As We May Think'.") In the *Atlantic* article, Bush proposed the development of a kind of work station, which he called a "memex," that would store and provide access to the equivalent of a million volumes of books. The memex would also employ a way of linking documents "whereby any item may be caused at will to select immediately and automatically another"—allowing the user to build a trail between multiple

Figure 9-4.
Internet domain survey host count



SOURCE: Internet Software Consortium. Available from <<http://www.isc.org/>>.

See appendix table 9-2.

Science & Engineering Indicators – 2000

documents. Although Bush proposed using photographic methods for storage and mechanical means for retrieval, and the exact technological capability he dreamed of has not yet come to pass, the proposed function of his memex is remarkably similar to hypertext today.

When Bush thought about the capabilities that would be dramatically useful to knowledge workers, he envisioned not capable calculators or word processors but capabilities to store and access information that current technology is just now achieving—using quite different approaches. Much R&D and innovation have been necessary to reach these capabilities.

In the same year that Bush's *Atlantic* article appeared, developments were taking place that would provide a different path for achieving his vision. At the University of Pennsylvania, John P. Eckert and John W. Mauchly were completing, with Army funding, what is commonly recognized as the first successful high-speed digital computer—the ENIAC. Dedicated in January 1946 and built at a cost of $487,802 (Moye 1996), the ENIAC used 18,000 vacuum tubes, covered 1,800 square feet of floor space, and consumed 180,000 watts of electrical power. It was programmed by wiring cable connections and setting 3,000 switches. It could perform 5,000 operations per second (CSTB 1998).

Also in 1945, Hungarian-born Princeton mathematician John von Neumann developed the stored program concept, which enabled computers to be programmed without rewiring. The von Neumann architecture—which refers to a computer with a central processing unit that executes instructions sequentially; a slow-to-access storage area; and secondary fast-access memory—became the basis for most of the computers that followed. Since the middle of the 20th century, software development has emerged as a discipline with its own challenges and skill requirements, complementing the more visible advances in hardware and enabling great systems complexity.

Over the succeeding 50 years, a vast number of innovations and developments occurred. (See sidebar, "IT Timeline.")

Innovations in IT over this period came from a remarkable diversity of sources and institutional settings, as well as a remarkable interplay among industry, universities, and government. Transistors and integrated circuits were invented by industry. Early computers and advances such as core memory, time-sharing, artificial intelligence, and Internet browsers were developed in universities, primarily with government funding. The World Wide Web was developed at the European Center for Particle Research (CERN), a high-energy physics laboratory. The mouse and windows were developed at a nonprofit research institute, with government funding. High-performance computers were mostly developed in industry with federal funds and with the involvement of federal laboratories. The diversity and close interaction between these institutions clearly contribute to the vitality of innovation in IT.

Innovation in IT has benefited from the support of a diverse set of federal agencies—including the Department of Defense (DOD), including the Defense Advanced Research Projects Agency (DARPA) and the services; NSF; the National Aeronautics and Space Administration (NASA); the Department of Energy (DOE); and the National Institutes of Health (NIH). Federal support has been particularly important in long-range fundamental research in areas such as computer architecture, computer graphics, and artificial intelligence, as well as in the development or procurement of large systems that advanced the technology—such as ARPANET, the Internet (See sidebar "Growth of the Internet"), and high-performance computers (CSTB 1998).

Often there has been complementary work supported by the Federal Government and industry. In many cases the Federal Government has supported the initial work in technolo-

Excerpts from "As We May Think"

Atlantic Monthly (July 1945)
by Vannevar Bush

Professionally our methods of transmitting and reviewing the results of research are generations old and by now are totally inadequate for their purpose...The difficulty seems to be, not so much that we publish unduly in view of the extent and variety of present day interests, but rather that publication has been extended far beyond our present ability to make real use of the record. The summation of human experience is being expanded at a prodigious rate, and the means we use for threading through the consequent maze to the momentarily important item is the same as was used in the days of square-rigged ships.

Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and, to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory.

It consists of a desk, and while it can presumably be operated from a distance, it is primarily the piece of furniture at which he works. On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and sets of buttons and levers. Otherwise it looks like an ordinary desk.

In one end is the stored material. The matter of bulk is well taken care of by improved microfilm. Only a small part of the interior of the memex is devoted to storage, the rest to mechanism. Yet if the user inserted 5,000 pages of material a day it would take him hundreds of years to fill the repository, so he can be profligate and enter material freely. It affords an immediate step…to associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex. The process of tying two items together is the important thing.

When the user is building a trail, he names it, inserts the name in a code book, and taps it out on his keyboard. Before him are the two items to be joined, projected onto adjacent viewing positions. At the bottom of each there are a number of blank code spaces, and a pointer is set to indicate one of these on each item. The user taps a single key, and the items are permanently joined. In each code space appears the code word. Out of view, but also in the code space, is inserted a set of dots for photocell viewing; and on each item these dots by their positions designate the index number of the other item.

Thereafter, at any time, when one of these items is in view, the other can be instantly recalled merely by tapping a button below the corresponding code space. Moreover, when numerous items have been thus joined together to form a trail, they can be reviewed in turn, rapidly or slowly, by deflecting a lever like that used for turning the pages of a book. It is exactly as though the physical items had been gathered together from widely separated sources and bound together to form a new book. It is more than this, for any item can be joined into numerous trails.

The owner of the memex, let us say, is interested in the origin and properties of the bow and arrow. Specifically he is studying why the short Turkish bow was apparently superior to the English long bow in the skirmishes of the Crusades. He has dozens of possibly pertinent books and articles in his memex.

First he runs through an encyclopedia, finds an interesting but sketchy article, leaves it projected. Next, in a history, he finds another pertinent item, and ties the two together. Thus he goes, building a trail of many items. Occasionally he inserts a comment of his own, either linking it into the main trail or joining it by a side trail to a particular item. When it becomes evident that the elastic properties of available materials had a great deal to do with the bow, he branches off on a side trail which takes him through textbooks on elasticity and tables of physical constants. He inserts a page of longhand analysis of his own. Thus he builds a trail of his interest through the maze of materials available to him.

gies that were later developed by the private sector. In other cases Federal research expanded on earlier industrial research. Higher-level computer languages were developed in industry and moved to universities. IBM pioneered relational databases and reduced-instruction-set computing, which were further developed with NSF support. Collaboration between industry and university researchers has facilitated the commercialization of computing research. (See figure 9-5.)[1]

Most of the relentless cost-cutting that has been so important in the expansion of IT has been driven by the private sector in response to competitive pressures in commercial markets, although here too federal investment—such as in semiconductor manufacturing technologies—has played an important role in some areas.

[1]For a more complete description of industry and government roles in developing information technologies, see CSTB (1998).

IT Timeline

1945: The ENIAC, the first high-speed digital computer, is built at the University of Pennsylvania for the U.S. Army's Ballistics Research Laboratory to help prepare artillery firing tables.

1947: Bell Telephone Laboratories develops the transistor.

1949: The concept for core memory is patented by An Wang at Harvard University. Core memory and random access memory (RAM) are further developed by the Whirlwind Project at MIT.

1951: UNIVAC, the first commercial computer, is developed and delivered to the Census Bureau.

1952: G.W. Dummer, a radar expert from the British Royal Radar Establishment, proposes that electronic equipment be manufactured as a solid block with no connecting wires; he receives little support for his research.

1953: IBM enters the computer business with the 700 series computer.

1959: Texas Instruments and Fairchild Semiconductor both announce the integrated circuit.

Late 1950s–early 1960s: Timesharing (the concept of linking a large numbers of users to a single computer via remote terminals) is developed at MIT.

1961: Fairchild Semiconductor markets the first commercial integrated circuits.

1964: The IBM 360 is introduced and becomes the standard institutional mainframe computer.

1965: Gordon Moore predicts that the number of components in an integrated circuit will double every year (Moore's Law).

1968: Doug Engelbart of Stanford Research Institute demonstrates a word processor, a mouse, an early hypertext system, and windows. Gordon Moore and Robert Noyce found Intel.

1969: ARPANET goes online. Xerox establishes the Palo Alto Research Center to explore the "architecture of information."

1970: Fairchild Semiconductor introduces a 256-bit RAM chip.

1971: Intel introduces the 4004, a 4-bit microprocessor.

1972: Intel introduces the 8008, the first 8-bit microprocessor. E-mail is introduced over ARPANET.

1973: Robert Kahn and Vinton Cerf develop the basic ideas of the Internet.

1975: The MITS Altair 8800 is hailed as the first "personal" computer. Paul Allen and Bill Gates develop BASIC for the Altair 8800.

1976: Microsoft and Apple are founded.

1977: Apple markets the Apple II for $1,195; it includes 16K of RAM but no monitor.

1979: Software Arts develops the first spreadsheet program, Visicalc, which is an immediate success.

1981: The IBM PC is released.

1982: TCP/IP (Transmission Control Protocol and Internet Protocol) is established as a standard for ARPANET.

1984: The Apple Macintosh is released, featuring a simple, graphical interface.

1986: NSF establishes NSFNET and five supercomputing centers.

1987: The number of network hosts exceeds 10,000.

1989: The number of network hosts exceeds 100,000.

1989: Microsoft's annual sales reach $1 billion. The World Wide Web is developed at CERN.

1992: The number of Internet hosts exceeds 1 million.

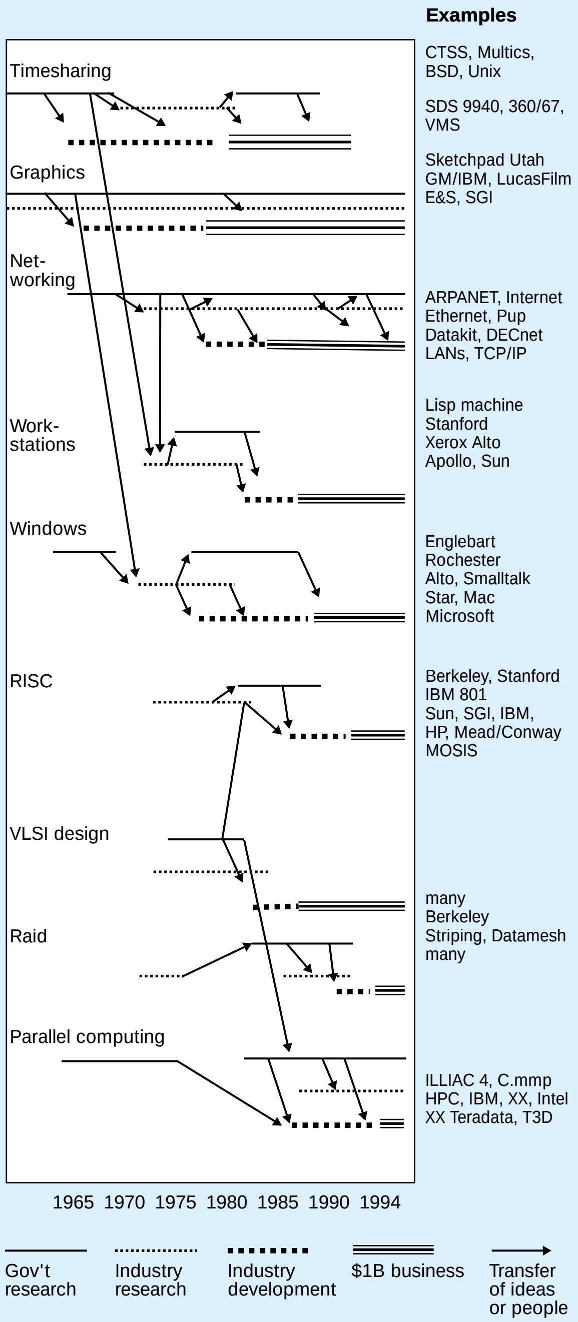
1993: Mosaic, the first Web browser, is developed at the NSF-funded National Center for Supercomputer Applications at the University of Illinois, leading to rapid growth of the World Wide Web.

1994: Main U.S. Internet backbone traffic begins routing through commercial providers.

1995: NSFNET privatized.

SOURCES: PBS Online companion Web site for television special "Triumph of the Nerds: The Rise of Accidental Empires," <<http://www.pbs.org/nerds/timeline/micro.html>>; Virginia Tech Virtual Museum of Computing, Chronology of Events in Computer History, <<http://video.cs.vt.edu:90/cgi-bin/Lobby?Method=Chronology>>; Leiner et al. (1998).

Figure 9-5.
Government support for computing research



SOURCE: National Research Council, Computer Science and Telecommunications Board, *Funding a Revolution; Government Support for Computed Research* (Washington, DC: National Academy Press, 1999). *Science & Engineering Indicators – 2000*

Growth of the Internet

The Internet is a meta-network for a variety of subnetworks and applications such as the World Wide Web, bulletin boards, Usenet newsgroups, e-mail, scientific data exchange, and more. The foundation for the Internet was ARPANET, which started as four computer nodes in 1969. ARPANET was initiated by DARPA and was based on a then-new telecommunications technology called packet switching. ARPANET flourished as a medium for information and data exchange among universities and research laboratories. Moreover, it stimulated the development of TCP/IP, a communications protocol that enabled the interconnection of diverse networks. By the late 1970s, ARPANET comprised hundreds of computer nodes and integrated several separate computer networks, including one based on satellite technology.

The Internet grew out of the ARPANET, which converted to the TCP/IP protocol in 1983. NSF sponsored CSNET and later NSFNET (a high-speed network to link supercomputing centers), which became the backbone for the Internet. NSFNET replaced ARPANET in 1990 and expanded to include a variety of regional networks that linked universities into the backbone network. Many smaller networks linked into NSFNET. By early 1994, commercial networks became widespread, and almost half of all registered users of the network were commercial entities.

Two other events dramatically reshaped the character of the Internet. First, in 1989, scientists at CERN developed the World Wide Web and introduced it in experimental form. Second, in 1993, a team of programmers at NSF's National Center for Supercomputing Applications at the University of Illinois introduced Mosaic, a graphical (hypermedia) browser for exploring the Web. Mosaic was made available on the Internet at no cost, and Web use soared. (See figure 9-4.)

NSFNET was fully privatized in 1995, when there were enough commercial Internet service providers, Web browsers, and search engines to sustain the network's operations and management. The Internet continues to evolve. The Next Generation Internet Initiative is developing a higher-speed, more functional telecommunications network.

For more information on the Internet, see Cerf (1997) and Leiner et al. (1998).

IT and the Economy

In recent years, there has been considerable discussion of the role of information technology in transforming the economy. Terms such as the "digital economy" (Tapscott 1996; U.S. Department of Commerce 1998, 1999a), the "Internet economy" (Center for Research in Electronic Commerce 1999), the "knowledge-based economy" (OECD 1999c), and the "new economy" (Atkinson and Court 1998) have come into common usage. Although these terms have somewhat different meanings, they all suggest that the U.S. economy is transforming in a way that produces higher productivity growth and greater innovation—and that personal computers, high-speed telecommunications, and the Internet are at the heart of this transformation.

Federal Reserve Chairman Alan Greenspan has recently begun to discuss the impact of IT on the economy: "Innovations in information technology—so-called IT—have begun to alter the manner in which we do business and create value, often in ways not readily foreseeable even five years ago" (Greenspan 1999). Greenspan credits information technologies with improving companies' knowledge of customers' needs, inventories, and material flows, enabling businesses to remove redundancies. He suggests that IT has also reduced delivery lead-times and streamlined the distribution system.

Large productivity increases and economic transformations, however, have been expected from information technologies for a long time. At least until recently, economists have found little evidence of expected productivity increases or other positive changes from information technology. It is appropriate, therefore, to approach statements about IT-induced transformations of the economy with a degree of caution.

The effect of IT on the economy is a large and complex issue. There are a variety of effects that vary according to the sector of the economy and the organizational and management practices of firms. Moreover, the effects may be rapidly changing as Internet-based electronic commerce expands. This section cannot cover in detail the full range of these issue; it focuses instead on evidence related to five questions:

- ♦ How is IT used in business?
- ♦ What are the effects of IT on productivity and economic growth?
- ♦ How has IT affected the composition of the economy?
- ♦ What are the effects of IT on income and employment?
- ♦ What are the international implications of electronic commerce?

Use of IT in Business

IT is being used in so many ways and in so many kinds of business that it is possible only to sketch that landscape here. At its most basic, IT automates a variety of activities, from control production systems in manufacturing to office-work basics such as word processing and financial calculations. In more sophisticated applications, IT involves databases and information retrieval that assist management, customer service, and logistics and aid product design, marketing, and competitive analysis. IT can combine computing and communications to support ordering and product tracking. These functions are often implemented as mechanization of older processes; ideally, however, they involve fundamental redesign of processes. These functions began using—and in many instances continue to rely on—components such as mainframe, mini-, and microcomputers, as well as telephone networks (the public switched network and leased-line private or virtual private networks). What marks the turn of the century is a move to broader integration of systems and, through them, enterprises. The spread of Internet technology and the proliferation of portable computing and communications devices have accelerated trends that began in past decades and now are hailed as "electronic commerce."

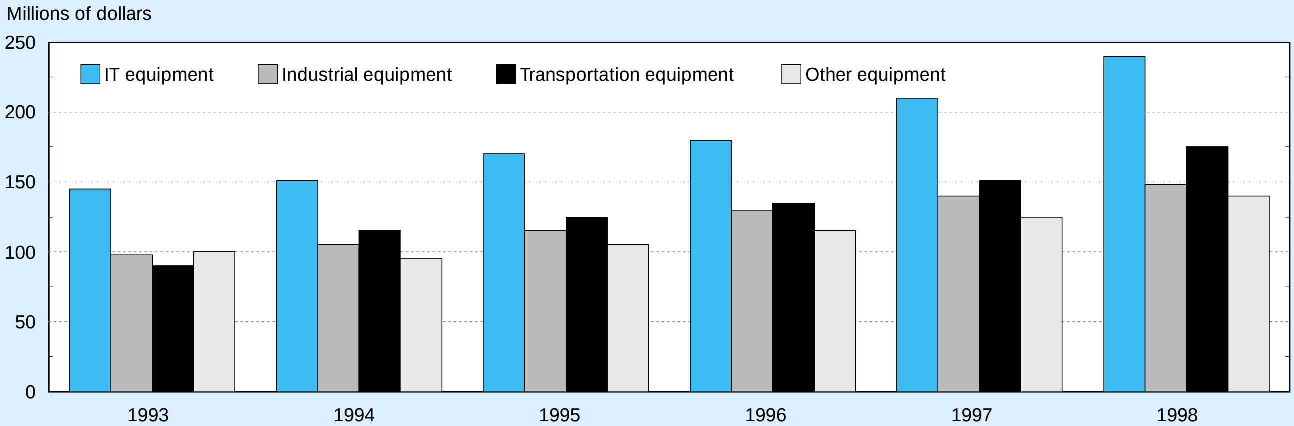
Although IT has the potential to transform business practices, there are substantial costs and barriers to implementation. IT equipment continues to be the largest category of industry spending for all types of capital equipment (including industrial equipment, transportation equipment, and other types of equipment). In current dollars, industry spending on IT equipment rose from $142 billion in 1993 to $233 billion in 1998. (See figure 9-6.)

Using IT in business is expensive not only in terms of initial costs but also in terms of the cost to maintain and upgrade the systems, train the people, and make the organizational changes required to benefit from IT. These costs may greatly exceed the original investment in IT equipment. Organizational changes often are especially difficult. Nevertheless, IT costs of all kinds are regarded as necessary elements for more and more businesses.

Electronic commerce (e-commerce) as a category of business use of IT deserves special attention because of its rapid growth and its potential to affect many business processes. The definition of electronic commerce is a matter of dispute. In one definition of e-commerce, transactions use Internet-based systems, rather than paper or proprietary electronic systems. By this definition, getting money from an ATM is not e-commerce, but transferring funds using the Web is. (See sidebar, "What is Electronic Commerce?")

E-commerce includes retail and business-to-business commerce. To date, business to business e-commerce has predominated. For example, Forrester Research projects that inter-company Internet commerce will reach $1.3 trillion by 2003 and that online retail trade will reach $184 billion by 2004 (Forrester Research 1998, 1999). In some cases—such as with flowers, books, computers, or industrial parts—the parties use the Internet to make the transaction, but the goods are still delivered physically. In other cases—such as with sales of software, electronic journals, or music—the goods may be delivered electronically. The mix of products made and sold through e-commerce is changing. The rise of electronic trading of securities illustrates the potential for considerable growth of essentially all-electronic business.

Figure 9-6.
Industry spending on IT equipment in the 1990s (current dollars)



SOURCE: U.S. Department of Commerce (1999a), *The Emerging Digital Economy II*, using data from the Bureau of Economic Analysis.

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What is Electronic Commerce?

Definitions of electronic commerce vary. Some definitions include all financial and commercial transactions that take place electronically, including electronic funds transfer (EFT), electronic data interchange (EDI), and credit card activity. These transactions have been going on for years and involve trillions of dollars of funds transfers per day (OECD 1999b). Other definitions limit e-commerce to transactions that take place entirely on open networks such as the Internet. These transactions are still in their infancy.

Definitions also differ in that some groups define e-commerce to include only transactions in which goods or services are ordered and paid for online, whereas other groups include transactions in which goods or services have been ordered, but not paid for, online.

The Organisation for Economic Co-operation and Development (OECD) and its member countries are working to develop standard definitions. OECD (1999b) and the U.S. Department of Commerce (1999a) define e-commerce as business occurring over networks that use nonproprietary protocols that are established through open standard-setting processes such as the Internet. The emphasis on the use of nonproprietary protocols is central. Earlier forms of electronic business, such as EDI and EFT, required preexisting relationships, specialized software, and dedicated communication links. Consequently, such commerce was used mainly to create two-way links between specific parties, such as large businesses and their main suppliers. Commerce over open systems such as the Internet allows communication between diverse computers and communications systems using standard interfaces. These interfaces allow communication among many different customers or suppliers without additional investment, lowering costs and vastly increasing options. This structure has made this form of commerce attractive to many more companies and consumers. Much of the rapidly expanding Internet-based e-commerce, however, is built on experience with earlier (non-Internet) forms of electronic business.

Retail e-commerce has spawned many new businesses that have no physical stores but can deliver a wide variety of goods on request. This mode of operating is often more economical than traditional retail stores. In response, many traditional retail stores have launched their own e-commerce strategies.

Another mode of retail e-commerce that has expanded rapidly is online auctions, which put buyers and sellers directly in touch with each other to negotiate a price. As of September 1999, eBay (one of the first and largest online auction enterprises) offered more than 3 million items for sale in more than 1,500 categories. Hundreds of other online auction enterprises have been established, and many other early e-commerce retailers—such as Amazon.com and Dell Computer—have added auctions as additional features of their Web sites. The mix of distribution channels is changing, and the extent to which new modes replace or complement the old remains to be seen.

Business-to-business e-commerce, like business-to-consumer e-commerce, can enable businesses to offer additional services and improved communication to their customers. Increased communication is enabling firms to outsource more easily, and to streamline and augment supply chain processes. It can also allow businesses to eliminate some intermediary organizations between customer and supplier and give rise to new classes of business intermediaries (such as online auctions). Because business-to-business e-commerce is built on the history of pre-Internet electronic transactions, there is substantial related expertise in place in many companies, and business-to-business e-commerce has expanded rapidly.

Although official nationwide government statistics for e-commerce have not yet been gathered, private studies and market research firms have collected information related to e-commerce. Although these estimates and forecasts do not agree on the definition or value of electronic commerce, they agree that Internet-based commerce is large and growing rapidly. (See text table 9-1.) The wide variation in the estimates reinforces the need for consistent definitions and data collection methods.

The growth of e-commerce has altered much of the discussion of the role of IT in the economy. Previously, much discussion had focused on the application of IT inside companies to improve their internal operations. Electronic commerce is shifting the focus to how businesses are using IT to communicate with customers and suppliers, including new distribution chains and new methods of marketing and selling. Because this arena appears to be changing so quickly, the effects of IT on the economy may change rapidly as well.

International Context of Electronic Commerce

Although the United States has been the world leader in information technology and especially in the Internet, these technologies are expanding rapidly around the globe. Several other countries match or are close to the United States in terms of penetration of personal computers into the home and the office. (See figures 9-7 and 9-8.)

Text table 9-1.
Forecasts of growth in Internet commerce

Study	Date	Result
Forrester Research	12/1998	U.S. inter-company trade of hard goods over the Internet will be $43 billion in 1998; $1.3 trillion in 2003.
University of Texas Center for Research in Electronic Commerce ...	5/1999	Value of 1998 Internet commerce was $102 billion.
International Data Corporation	6/1999	Internet-based worldwide commerce to reach $1 trillion by 2003.

SOURCES: Center for Research in Electronic Commerce (1999), Forrester Research (1998), and International Data Corporation (1999).

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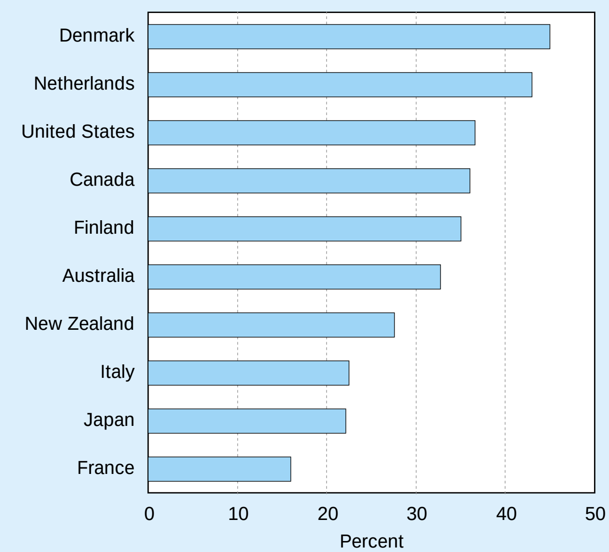
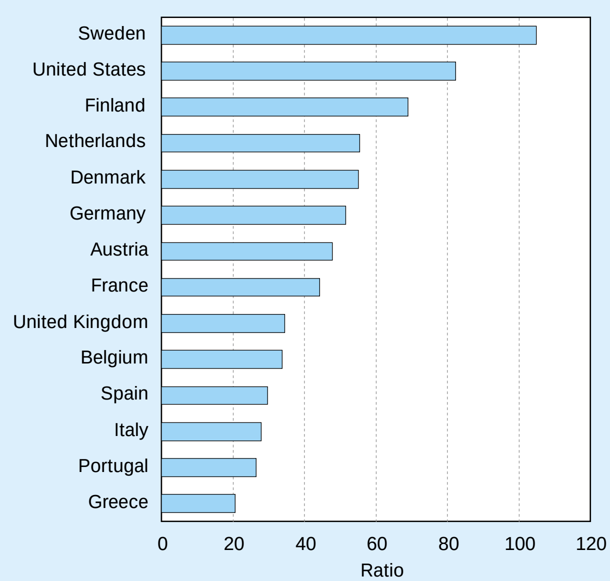
The Scandinavian countries and Canada roughly match the United States in the number of Internet hosts per capita; Finland exceeds the United States in this measure. (See figure 9-9.) Based on the number of secure Web servers (those using encryption and third-party certification, which are suitable for e-commerce) per 100,000 inhabitants, the United States is one of the leading countries in e-commerce, but

Figure 9-7.
PC penetration in households, 1997 or latest year



SOURCE: OECD, compiled from National Statistical Offices, March 1999. *Science & Engineering Indicators – 2000*

Figure 9-8.
PCs per 100 white-collar workers, 1997



SOURCE: OECD, based on ILO and IDC data, March 1999.

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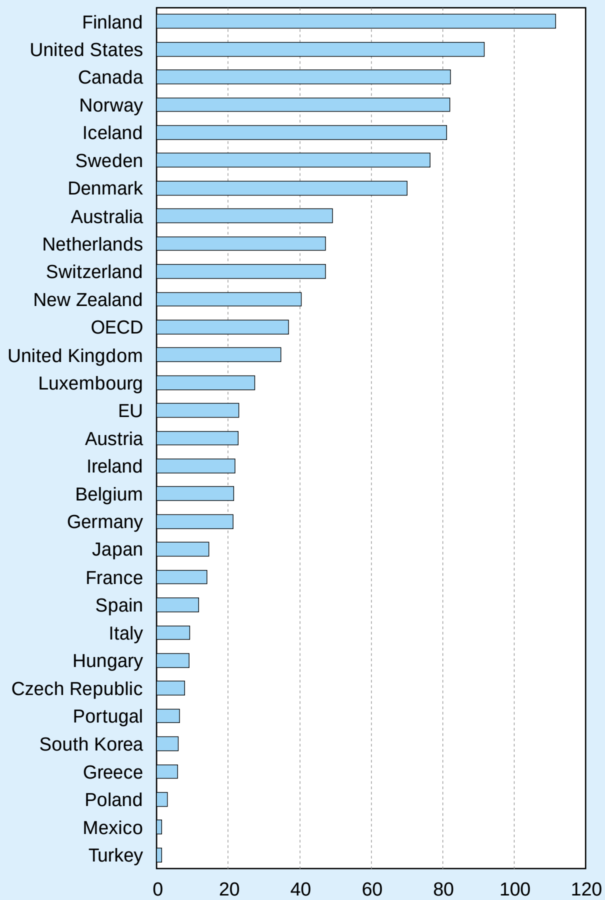
Figure 9-9.
Number of Internet hosts per 1,000 inhabitants: January 1999



SOURCE: Network Wizards and OECD.

Science & Engineering Indicators – 2000

servers suitable for e-commerce are dispersing around the globe. (See figure 9-10.) Countries other than the United States are expected to account for almost half of worldwide Internet commerce by 2003 (IDC 1999).

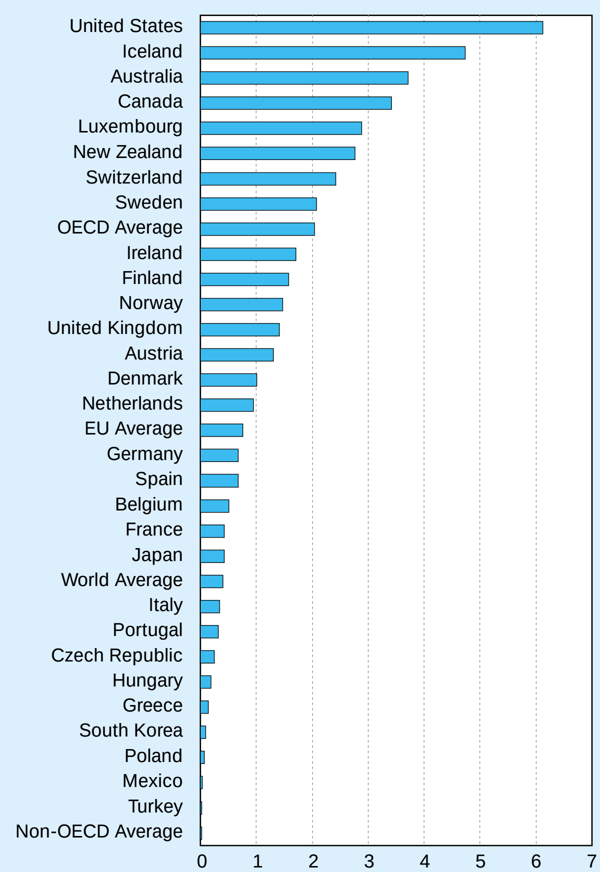
The international diffusion of e-commerce raises many policy issues. On the Internet, information crosses national borders readily, cheaply, and freely. Transactions involving the citizens of one country may fall under the jurisdiction of another country with different laws and regulations governing the transaction. The laws and regulations of many nations frequently come into conflict. For example, trademarks posted in the Internet in one country may violate trademarks in another country. Advertising that is legal in one country may be illegal or objectionable in countries whose residents can view the information on the Web. Collection and use of personal information on Web sites may be legal in one country and illegal in another. International e-commerce may find itself subject to ambiguous or duplicative tax, contract, and intellectual property laws. Although many of these issues have some precedents in the pre-Internet world, they are amplified by the expansion and diffusion of e-commerce. Many small companies without multinational operational or legal experience are increasingly engaged in international markets. E-commerce appears to lower barriers to entry and levels the playing field between large and small companies and large and small countries. E-commerce also appears to be putting pressure on countries around the world to create more harmonized legal environments, working through multinational and nongovernmental organizations.

Effects of IT on Productivity and Economic Growth

Productivity

In spite of the investment in and obvious capabilities of IT, there has been little evidence—until recently—that IT has improved productivity in the aggregate. Solow (1987) termed this inability to find a statistical association between IT investments and productivity in the private sector the “productivity paradox.” Many econometric analyses have failed to

Figure 9-10.
Secure Web servers for electronic commerce per 100,000 inhabitants: August 1998



SOURCE: OECD Communications Outlook 1999.

Science & Engineering Indicators – 2000

find any productivity benefits for IT (for reviews of this literature, see Brynjolfsson and Yang 1996 and CSTB 1994a). These studies failed to find a positive and significant contribution of IT to productivity in any sector (neither services nor manufacturing), by any measure (a variety of data sets and methods were used), at any level of analysis (the macroeconomy or specific industries and sectors), or at any time (from the late 1960s to the late 1980s). Positive effects were found only in limited case studies of a single industry or small set of firms.

Brynjolfsson and Hitt (1995, 1996, 1998), however, have found large and significant contributions by IT to productivity using a firm-level database. Every additional dollar of computer capital stock was associated with an increase in marginal output of 81 cents, and every additional dollar spent on IT-related labor was associated with an increase in marginal output of $2.62. Brynjolfsson and Hitt found that although there is a positive correlation between IT and productivity, there is substantial variation between firms. Firm-level variables can account for half of the variation in IT's contribution to marginal productivity. This finding suggests that the effectiveness of IT depends on how a firm uses it. Brynjolfsson and Hitt (1998) conclude that although computerization does not automatically increase productivity, it is an essential component of a broader system of organizational change that does.

Several factors may explain the contrast between the findings of Brynjolfsson and Hitt and the earlier productivity studies. The later time period of their study (1987–91); the use of a larger data set; more detailed, firm-level data; and the inclusion of IT-related labor may all be reasons why their findings are more positive than those resulting from earlier research. Using similar data and methods, other analysts have also found significant positive rates of return at the firm level, including Lichtenberg (1995) and Link and Scott (1998).

Oliner and Sichel (1994) found that from 1970 to 1992, computer hardware contributed 0.15 percentage points to the total U.S. output growth rate of 2.8 percent. When software and computer-related labor are included, this contribution doubles to 0.31 percentage points for the period 1987–93 (11 percent of total growth). Other capital and labor inputs, as well as multifactor productivity gains, account for about 90 percent of the growth in U.S. output during this period. Oliner and Sichel note that computing-related inputs are a very small portion of total capital and labor and have only recently grown large enough to have a measurable impact. They conclude that "computing equipment can be productive at the firm level and yet make little contribution to aggregate growth, precisely because computers remain a relatively minor factor of production" (Oliner and Sichel 1994, 286).

More recently, the U.S. Department of Commerce has examined the gross product originating—or value added—per worker (GPO/W) as a measure of productivity (U.S. Department of Commerce 1999a). Nonfarm industries were divided into IT-producing, IT-using, and non–IT-intensive and then further divided into goods and services industries. IT-producing industries have experienced strong growth in GPO/W; in contrast, IT-using industries, especially in the services, have experienced slight GPO/W shrinkage. (See text table 9-2.)

Although growth in GPO/W was greater for IT-using industries than for non–IT-intensive industries in the goods producing sector, it was less for IT-using industries than for non–IT-intensive industries in the services sector.

There are two common explanations for the productivity paradox. First, there are measurement problems. As Brynjolfsson and Hitt (1998) observe, two aspects of productivity have increasingly defied precise measurement: output and input. The measurement problems are substantial (Baily and Chakrabarti 1988; Brynjolfsson 1993; CSTB 1994a; Griliches 1997; Oliner and Sichel 1994).

Regarding inputs, there are issues about what constitutes IT. Is it capital investments only, or does it include labor (which represents the bulk of IT operating costs)? Do IT capital investments include more than computers and software, and if so, what? Choices about what to count as an IT equipment expense include computing hardware and software, communications equipment, and a variety of office machines (such as photocopiers and some instruments). This choice is further complicated by the fact that IT is increasingly embedded in other systems, such as machine tools, automobiles, and appliances. At present, there is little consistency among studies, and sources of IT investment data vary from aggregate government data to private survey-based firm data.

Another measurement issue is how to assign dollar values to IT as a factor input. IT can be measured as a flow (annual expenses or purchases) or as a stock (the cumulation of equipment over time). In both instances, price deflators are required to compare stocks or flows over time by converting them to "real" dollars. IT equipment is especially problematic for establishing reliable deflators. For example, not only has the sales price of computing equipment been falling rapidly, but because quality has increased exponentially, existing computing stock becomes obsolete very quickly and therefore is difficult to evaluate adequately.

The pace of technological change in IT greatly complicates analysts' abilities to construct quality-adjusted price deflators and appropriate depreciation rates. The Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS) have developed price indices that reflect changes in IT quality. The values used significantly affect research outcomes by influencing the value of expenses and stocks in different periods.

A third measurement difficulty relates to how to measure the output of information processing. IT is used extensively for activities that do not result in tangible market outputs (e.g., accounting, scheduling, reporting). Consequently, it is difficult to assign a dollar value to the output of IT—a measurement that is essential for accurate productivity analysis. This measurement challenge is exacerbated in the services sector, where output measures must also capture qualitative differences in services (Mark 1982, Noyelle 1990). Services are hard to measure; according to Department of Commerce classification, almost 90 percent of the nonfarm U.S. economy

Text table 9-2.
Gross product originating per worker, annual growth rate: 1990–97

Gross product	Annual growth rate (1990–97)
Total private nonfarm	1.4
IT-producing	10.4
Goods	23.9
Services	5.8
IT-using	-0.1
Goods	2.4
Services	-0.3
Non-IT intensive	1.1
Goods	1.3
Services	1.3
All industries other than IT-producing	0.5

SOURCE: U.S. Department of Commerce, *The Emerging Digital Economy II.* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>.

Science & Engineering Indicators – 2000

that is IT-using is in the service sector.[2] (See text table 9-3.)

A fourth measurement issue concerns how to value IT benefits that do not show up as classical efficiency gains, such as qualitative improvements in customer service. These benefits might include enhanced timeliness, performance, functionality, flexibility, accuracy, precision, customization, cycle times, variety, and responsiveness (Bradley, Hausman, and Nolan 1993; Byrne 1996; CSTB 1994a). These qualitative dimensions are much more likely to show up as downstream benefits to the consumer (Bresnahan 1986) or as greater competitiveness for a firm (Baily and Chakrabarti 1988; Banker and Kauffman 1988; Brynjolfsson 1993; Porter and Millar 1985).

Another explanation of the productivity paradox is that it is a real but temporary phenomenon. Sociologists and economic historians have long argued that society's ability to fully exploit a new technology lags—often by decades—introduction of the technology itself (Ogburn 1964, Perez 1983). Similarly, in organizational change scholarship, institutional resistance to change is the norm. David (1989) found, for example, that nearly 20 years elapsed before the electric generator—an invention comparable to IT in scope and consequence—had a measurable effect on industrial productivity. With respect to IT specifically, firm-level performance can vary considerably, and the effective use of IT is apparently contingent on moderating variables at the organizational level—including strategy, leadership, attitudes, organizational structure, appropriate task and process reengineering, individual and organizational learning, and managerial style and decisionmaking (Allen and Morton 1994; Banker, Kauffman, and Mahmood 1993; Cron and Sobol 1983; Curley and Pyburn 1982; Danziger and Kraemer 1986; Graham 1976; Khosrowpour 1994; Landauer 1995; Tapscott 1996; Thurow 1987).

[2]Agriculture can also be IT-intensive.

The banking and trucking industries are two very different sectors that illustrate some of the effects—and some of the difficulties in measuring those effects—of IT in specific sectors. (See sidebars, "IT and the Banking Industry" and "IT and the Trucking Industry.") The banking industry is a white-collar service industry that has long been at the forefront of IT use. The trucking industry is a predominately blue-collar industry that has not been considered IT-intensive. IT has strong but difficult to measure effects on productivity and work in both of these industries.

Effects on Inflation and Growth

IT appears to be having positive effects on inflation and growth in the economy as a whole. These effects relate primarily to growth and declining prices in the IT sector rather than the effects of application of IT.

The U.S. Department of Commerce (1999a) found that declining prices in IT-producing industries have helped to reduce inflation in the economy as a whole. (See text table 9-4.) Decreasing IT costs may also have helped other industries control their costs. The department also found that IT-producing industries have contributed substantially to economic growth in the United States. The department estimates that over the past four years, IT industries have contributed more than one-third of the growth of real output for the overall economy. (See text table 9-5.)

Effects on Composition of the Economy

In addition to causing changes in the overall economy, IT is causing changes in the structure of the economy. One obvious change is growth in the IT-producing sector. Because that sector has been growing faster than the economy as a whole, its share of the economy has increased. (See figure 9-12.)

IT also is commonly credited as a key factor in the structural shift from manufacturing to services in the U.S. economy. Growth in existing services such as banking and the creation of new industries such as software engineering are attributed to the widespread diffusion of IT (CSTB 1994a, Link and Scott 1998). From 1959 to 1997, the service sector grew from 49 percent of U.S. gross domestic product (GDP) to 64 per-

Text table 9-3.
Percentage share of total private nonfarm gross product originating by sector, United States: 1990–97

Sector	Goods	Services	Total
IT-producing	2.0	6.2	8.2
IT-using	5.0	43.3	48.3
Non-IT intensive	23.0	20.6	43.6
Total	30.0	70.0	100.0

SOURCE: U.S. Department of Commerce, *The Emerging Digital Economy II.* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>.

See appendix table 9-3. *Science & Engineering Indicators – 2000* cent of GDP, while manufacturing declined from 28 percent of GDP to 17 percent of GDP.

The expansion of the service sector has been driven by industries that are often classified as "knowledge" industries (see Machlup 1962)—finance, insurance, and real estate (FIRE)—as well as professional services such as health and education. The share of GDP accounted for by wholesale and retail trade declined from 1959 to 1997, while personal services and transportation and utilities remained essentially unchanged. (See appendix table 9-4.) In contrast, FIRE's share of GDP grew by 5.8 percentage points, and that of professional services increased by 7.7 percentage points.

IT and the Banking Industry

The banking industry reflects most of the empirical dilemmas associated with measuring the impacts of IT: heavy investment in IT; little measurable improvement in productivity traced to IT; and effects that reflect quality improvements, rapid product diversification, and substantial growth in volume of commercial transactions. IT has changed the structure and service quality of banking and appears to have a positive effect on cost reduction. It has taken decades to achieve these results, however, and traditional productivity analyses still do not detect positive associations between IT investments and productivity in the commercial banking sector.

Banking industry investments in IT increased substantially from the late 1960s to the late 1980s. Annual investments in IT (in constant 1982 dollars) grew from $0.1 billion in 1969 to $1.6 billion in 1980 to $13.8 billion in 1989 (CTSB 1994a). By 1989, the banking industry was investing more funds in IT annually than all of the other major service industries except telecommunications.

IT applications in banking included accounts management and check processing via magnetic ink character recognition. Automated clearinghouses, which enabled electronic funds transfer (EFT), were introduced in the early 1970s, and ATMs were introduced in the late 1970s. EFT, ATMs, and telephone transaction capabilities have replaced a wide variety of paper and in-person transactions in banking, including account deposits and withdrawals, accounts management, credit applications and approvals, cash dispensing, funds transfers, point-of-sale transactions, credit card payments, and consolidation of banking operations.

Major cross-sector studies (see Brynjolfsson and Yang 1996 for reviews), however, failed to detect positive productivity returns for IT in the banking industry, and Franke's (1989) study of the financial sector (insurance and banking combined) suggested that IT is associated with negative productivity effects. On the other hand, labor productivity has been steadily improving in the banking industry. Productivity improved substantially from 1982 through 1997. The difficulty is in empirically linking these improvements to investment in IT.

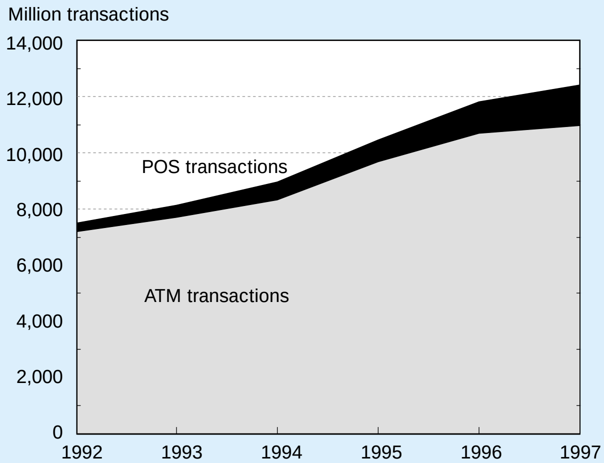
IT-related productivity growth may have been slow because of problems with early generations of information technologies and organizational adaptation. The National Research Council reported that early applications of IT were costly and cumbersome; software and equipment had to be updated and replaced frequently, and IT systems required large amounts of tailoring, training, upgrading, and updating. Cost control, management skills, and productivity tracking systems lagged the new technologies in a rapidly changing, competitive marketplace (CSTB 1994a, 80–81).

In addition, many of the benefits of IT were in areas that productivity indicators did not capture. These benefits included expansion of banking products and services, time and cost savings, and competitive positioning. Banking products and services have proliferated with the use of EFT, ATMs, telephone transactions, and automated credit and loan procedures. Banks thus process billions of transactions a year—including clearing individual checks, ATM cash dispersal, account inquiries, and loan approvals—a volume of interactions that would not be possible without automation. For example, automated clearing house payments, which include direct deposit of payroll payments, expense reimbursements, government benefits and tax refunds, and direct payments of bills, totaled more that 5.3 billion payments worth $16.4 trillion in 1998 (National Automated Clearing House Association 1999). The number of electronic cash transactions and payments for goods and services was more than 12 billion in 1997, compared with 7.5 billion in 1992. (See figure 9-11.)

Bresnahan (1986) estimates that the benefits to consumers from the use of mainframe computers for financial services were five times greater than the investments in the computers themselves. Qualitative improvement in customer convenience, ease, and scope of access to financial resources is reflected in the overall growth of electronic transactions. Time and cost savings for the industry are also notable. The processing time for credit card authorizations has shrunk dramatically, and banks have been able to reduce their staffs while increasing the number of transactions (CSTB 1994a, 83–84). ATM transactions cost an estimated 27 cents, compared to $1.07 for a human teller transaction; automated telephone transactions cost about $0.35, compared to $1.82 for a phone call processed by bank personnel (Morisi 1996). In a study of 759 banks, Alpar and Kim (1991) found that a 10 percent increase in IT expenses led to a 1.9 percent decrease in total bank costs.

Although productivity measures do not find a link between banking industry output and IT investments, it is important to note that while the volume of financial transactions has been increasing at a dramatic rate, employment in the sector has been falling. By 1996, employment in the commercial banking industry was 100,000 employees below its historic peak in 1990.

Figure 9-11.
U.S. electronic funds transfer volume



NOTES: Electronic funds transfer includes automated teller machine (ATM) transactions and transactions at point-of-sale (POS) terminals. POS terminals are electronic terminals in retail stores that allow a customer to pay for goods through a direct debit to a customer's account at the bank.

SOURCE: Statistical Abstract of the United States, table 825. Data from: Faulkner & Gray, Chicago, IL, Faulkner & Gray/EFT Network Data Book-1998. September 26, 1997 (copyright).

Science & Engineering Indicators – 2000

IT has not been empirically linked in a definitive way to the expansion of the service sector, however. In a detailed study of several key service industries (banking, insurance, air transport, and telecommunications), the National Research Council concluded that although the benefits of IT for individual industries could be qualitatively described, IT could not be causally linked to gross product output of the individual industry for methodological reasons (CSTB 1994a). Expansion of the air transport, banking, finance, and trade industries probably would not have been as great in the absence of IT (CSTB 1994a). Moreover, IT is particularly concentrated in service industries that have experienced rapid expansion.

IT may also be contributing to other shifts in the economy. Home based e-commerce may be displacing traditional banking, travel, legal, and educational services to some extent. To the extent that home-based IT replaces services that previously were paid for and captured in economic indicators, this effect may lead to an understatement of economic growth. To date, home users have been disproportionately persons with higher income and more education (see chapter 8, "Science and Technology: Public Attitudes and Public Understanding" and "IT and the Citizen" in this chapter). If that pattern persists, the distribution of real income, including nonmarket production, may become less equitable. Understanding the distribution of work between the household and the market may once again emerge as a critical element in understanding economic growth.

IT and the Trucking Industry*

Transportation is an important sector of the U.S. economy. Nearly 75 percent of all freight is transported by truck at some point in the distribution chain. Many changes have occurred in the industry over the past 15 years—reflecting deregulation, increased fuel efficiency, and increased sizes of trucks. More recent changes have related to the use of IT, including scheduling, dispatching, and onboard communications systems (such as cellular phones and computers).

Existing evidence suggests a substantial boost in productivity from rather modest investments in IT—particularly from more effective routing and scheduling, such as with "just-in-time" delivery systems. This productivity increase is important because trucking is not one of the industries that shows up as substantially dependent on IT. Trucking is not considered an IT-dependent industry in terms of IT expenditures as a share of capital costs or IT per worker. Yet with input from sources external to the industry, IT appears to play a significant role in trucking.

Approaches to the use of IT are heterogeneous at the firm level. Some trucking firms have been innovative leaders, others distant followers; still other firms have been operating in crisis mode to catch up to the rest of the fleet. Investment in IT may not correlate directly to productivity because the innovative leaders and firms acting in crisis mode may spend more—but less cost-effectively—on IT than the distant followers. The lack of training of the workforce and limited IT training of managers seems not to be fatal in the adoption of IT. Many workers make only passive use of the technology. Rising productivity may benefit company earnings and consumers more than it benefits drivers, who do not appear to receive pay increases that reflect their increased productivity. IT benefits also may accrue to those who develop and implement the dispatching software systems, rather than to drivers.

*The information in this box is based on the work of the University of Michigan Trucking Industry Program (UMTIP). See Belman et al. (1998) and Nagarajan et al. (1999).

Effects on Income and Employment

Information technology creates some new jobs and eliminates others. As jobs are created or eliminated, the labor markets adjust in complex ways. Wages go up in areas where the demand for skills exceeds the supply and go down in areas where there are more jobs than workers. Over time, the effects of IT are likely to appear not in unemployment figures but in the wages of different occupations.

In a review of the literature on computerization and wages, Katz (1999) notes that many authors have found that wage inequities and educational wage differentials have increased in the United States in the past two decades—coinciding with

Text table 9-4.
Price changes, IT-producing and all other industries

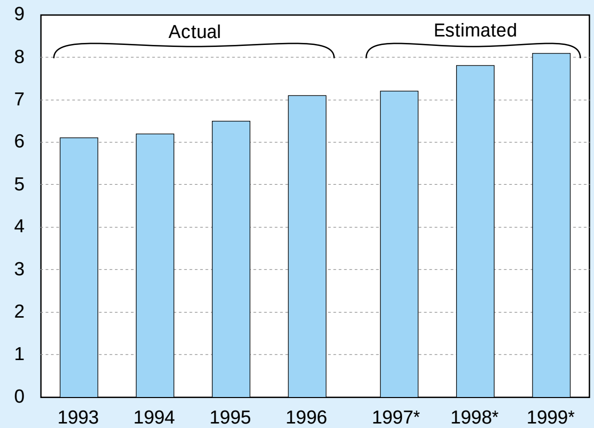
	1993	1994	1995	1996	1997
IT-producing industries	–2.4	–2.6	–4.9	–7.0	–7.5
Rest of the economy	3.0	2.7	2.8	2.6	2.6
GDP	2.6	2.4	2.3	1.9	1.9

SOURCE: U.S. Department of Commerce, *The Emerging Digital Workforce II.* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>. Based on BEA and Census data.

See appendix table 9-3.

Science & Engineering Indicators – 2000

Figure 9-12.
IT-producing industries' share of the economy: 1993–99



SOURCES: U.S. Department of Commerce, *The Emerging Digital Economy II* (Washington, DC: 1999). Available from <<http://www.ecommerce.gov>>. ESA estimates derived from BEA and Census data for 1993–1996. ESA estimates for 1997-1999 derived using DOC's "Industry and Trade Outook."

Science & Engineering Indicators – 2000

the computerization of the workplace. From 1973 to 1995, wages have increased in the top 30 percentiles and have decreased in the bottom 70. (See appendix table 9-10.) Rising wages and labor income of educated workers, combined with rising relative supply, are consistent with a model in which IT allows skilled workers to produce things previously in the domain of the less-skilled. This trend deteriorates the terms of trade of the less skilled workers, reducing their relative income (Gomery 1994, Johnson and Stafford 1998).

Katz (1999) notes that relative employment and wages have both increased within industries for more educated workers during the 1980s and 1990s, indicating shifts favoring more skilled workers. He finds that skill-based and organizational changes that have accompanied the computer revolution appear to have contributed to faster growth in the demand for skilled labor starting in the 1970s. Factors other than technological change—including the slowdown in the increase of college-educated people entering the labor force, globalization (especially outsourcing of low-skilled work), and the weakening of unions—may also play a role in creating rising wage inequities, however.

Although evidence suggests that IT should increase the demand for workers who manipulate and analyze information relative to the demand for non-knowledge workers or those who simply enter and collate data, there is also a popular fear that automation will reduce the demands on an individual's conceptual talents and facility with machinery, equipment, and tools. Individual case studies of specific industries, occupations, and information technologies illustrate that IT can sometimes reduce and sometimes increase the skills required in particular jobs (for reviews, see Attewell and Rule 1994, Cyert and Mowery 1987).

On balance, however, several studies—using different data sets and methodologies—suggest that no overall lessening of skills is occurring in the workforce and that upgrading may be widespread. For example, Castells (1996) finds that em-

Text table 9-5.
IT-producing industries: contribution to real economic growth

	1993	1994	1995	1996	1997 est.	1998 est.
(1) Change in real gross domestic income* (GDI)	2.2	4.1	2.9	3.5	4.2	4.1
Percentage points						
(2) IT contribution	0.6	0.6	1.2	1.5	1.2	1.2
(3) All other industries	1.6	3.5	1.7	2.0	3.0	2.9
(4) IT portion (percent) of GDI change (2)÷(1)	26.0	15.0	41.0	42.0	28.0	29.0

*GDI is equal to the income that originates in the production of goods and services attributable to labor and property located in the United States.

SOURCE: U.S. Department of Commerce (1999) from ESA estimates derived from BEA and Census data for 1993–96. ESA estimates for 1997–98 derived from DOC's "Industry and Trade Outlook '99."

See appendix table 9-3.

Science & Engineering Indicators – 2000

ployment in managerial, professional, and technical classes has been expanding at a faster rate than employment in non- and semi-skilled occupations. Howell and Wolff (1993) reach much the same conclusion; using detailed data on cognitive and motor skills required for specific occupations from 1959 to 1990, they found that skill restructuring (principally upgrading) in the labor force began in the 1970s and continued in the 1980s in patterns that are "broadly consistent with what one might expect from the rapid expansion of new [information] technology" (Howell and Wolff 1993, 12). Howell and Wolff also found that demand for the most cognitively skilled information occupations grew more rapidly than demand for other occupations during some periods. Analyzing data from the Annual Survey of Manufacturers, Berman, Bound, and Griliches (1994) document significant skill upgrading throughout the manufacturing sector during the 1980s—which they attribute in part to computerization of the workplace. Their findings indicate a distinct shift in the demand for labor in the United States from less skilled to more highly (cognitively) skilled labor—a shift that has been linked theoretically and empirically to the diffusion of IT. Autor, Katz, and Krueger (1997) found that those industries that experienced the largest growth in computer use also tended to shift their employee mix from administrative and support workers toward managers and professionals (a finding consistent with Castells 1996).

In addition to the effects of IT on wages, Katz (1999) identifies several other issues relating to IT and employment that merit further study. For example, how does the growth of the Internet affect the geographic distribution of work among large cities, smaller cities, suburban areas, and rural areas? What is the promise of telecommuting, and what is the reality? What are the sources of employee training in the rapidly changing digital economy? How do Internet job searching and computer-oriented labor market intermediaries (e.g., the temporary help industry) affect the labor market? These topics suggest a rich area for further study.

IT Workforce

With rapid expansion of IT development and application, and with the overall U.S. economy running at full employment, it is not surprising that there have been recent concerns about the availability of IT workers. Demand for IT workers has been growing steadily for years. (See figure 9-13.)

The IT industry itself has asserted that there is a serious shortage of IT workers. The U.S. Department of Commerce (1997, 1999b) published Bureau of Labor Statistics projections on future U.S. demand for three core occupational classifications of IT workers—computer scientists and engineers, systems analysts, and computer programmers. These projections indicated that between 1996 and 2006, the United States would require more than 1.3 million new IT workers in these three occupations. (See text table 9-6.)

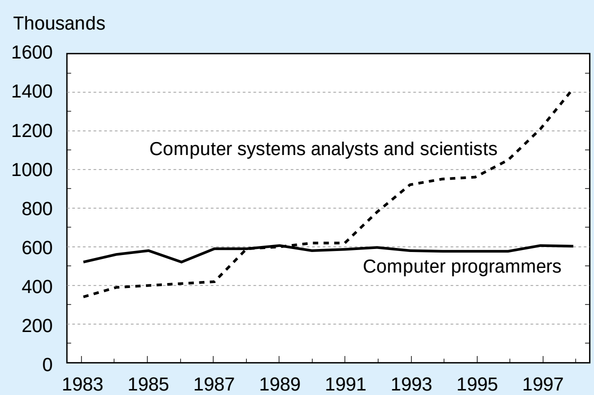
After increasing sharply in the early 1980s, the number of computer science degrees awarded declined sharply after 1986 and has been flat for the past few years. (See chapter 4, "Higher Education in Science and Engineering.")

The assertion that there is a shortage of IT workers has been contentious. Although many people in industry believe that they need more IT-trained workers to meet the growing demand, some employee groups believe that there are enough trained technical professionals in the United States—but that industry has not tapped these existing labor pools (especially older engineers). The debate has been especially polarized over the issue of whether to allow more foreign technically trained workers to enter the country on temporary H-1B visas.

Other studies have examined the IT workforce issue (Freeman and Aspray 1999, Johnson and Bobo 1998, Lerman 1998, U.S. Department of Commerce 1999b; see also chapter 3, "Science and Engineering Workforce"). These studies have generally concluded that:

- The IT labor market appears to be tight (to a somewhat greater extent than the overall job market), but existing data cannot prove or disprove that there is a shortage. Federal data are limited by untimely reporting, out-of-date occupational descriptions, and incompatibilities between supply and demand data collected by different agencies.
- The IT labor market is not homogeneous. Supply and demand characteristics vary by region, by industry segment, and by specific skills. Because product cycle times are very fast in much of the IT industry, a premium is paid for people with specific current skills rather than people who require training to be effective. Competition is especially intense for people with specific "hot" skills in specific markets.
- People enter IT careers from a variety of directions. IT workers include people who majored in IT-related disciplines at the associate, bachelor's, master's, and doctoral

Figure 9-13.
Employment in core IT occupations: 1983–98



SOURCE: U.S. Department of Commerce, *The Digital Workforce: Building Infotech Skills at the Speed of Innovation* (Washington, DC: 1999). Available from <<http://www.ta.doc.gov/reports/itsw/digital.pdf>>.

Science & Engineering Indicators – 2000

Text table 9-6.
Employment projections for core IT occupations
(Thousands)

Occupation	Employment 1996	Employment 2006	Change, 1996-2006 Number	Change, 1996-2006 Percentage	Net Replacements	Total Job Openings (growth and net replacement)
Computer scientists	212	461	249	118	19	268
Computer engineers	216	451	235	109	15	250
Systems analysts	506	1,025	520	103	34	554
Computer programmers	568	697	129	23	177	306
Total	1,502	2,634	1,133	75	245	1,378

SOURCE: U.S. Department of Commerce, *The Digital Work Force: Building Infotech Skills at the Speed of Innovation.* (Washington, DC: 1999); and U.S. Department of Labor Statistics, 1996 industry-occupation employment matrix.

Science & Engineering Indicators – 2000

levels; people from other science, engineering, and business fields; and people from nontechnical disciplines who have taken some courses in IT subjects. Many people also enter the field through continuing education programs and for-profit schools. New modes of instruction delivery, such as distance learning are being used. (See "Distance Education.")

- The job market is showing signs of responding—if imperfectly—to the tight IT labor markets. Wage increases are attracting more people to the field. A large number of initiatives around the country have been started to address the problem. Enrollments are increasing in training programs and in 4-year degree programs.

IT and Education

Information technologies are likely to have a substantial effect on the entire spectrum of education by affecting how we learn, what we know, and where we obtain knowledge and information. IT influences the creation of scientifically derived knowledge; how children learn in schools; lifelong learning by adults; and the storage of a society's cumulative knowledge, history, and culture. IT can bring new information and types of instruction into the classroom; it can provide students with new tools for finding and manipulating information; and it can provide resources that are not available in a particular geographical area. At the same time, IT may impose new costs in equipment, software, and the time it takes to learn new systems; it also threatens to disrupt existing methods of knowledge creation and transfer, as well as the archiving of knowledge.

This section reviews the role of IT in classrooms, in distance education, in the storage and dissemination of knowledge, and in the creation of new knowledge. In each of these areas, similar technologies can be applied from K–12 education to leading-edge research. Much of the attention in each of these categories, however, is directed at one level. Most discussion of IT in the classroom, for example, focuses on K–12 education. Distance education is being used most in higher education. Discussion of the creation, storage, and dissemination of knowledge focuses on the research community. Although this discussion concentrates on these areas, virtually all of the technologies discussed here can be used—and are being used—at many levels in the education/research system. Other chapters of this report discuss the use of information technology in specific parts of the education system: For example, chapter 5 discusses IT at the K–12 level.

IT in the Classroom

In recent years there has been a great deal of emphasis in the United States on increasing the use of information technologies in U.S. elementary and secondary schools (Children's Partnership 1996, McKinsey and Company 1995, NIIAC 1995, PCAST 1997). Greater use of IT at the precollege level is frequently regarded as providing the training students need to be competent members of the information society and to enjoy the benefits of information technology. Schools are expected to expose all children to information technologies so society does not become stratified into information-rich and information-poor classes. A 1992 survey of elementary and high school principals found that the three main reasons schools adopt computer technologies are to give students the experience they will need with computers for the future, to keep the curriculum and teaching methods current, and to improve student achievement (Pelgrum, Janssen, and Plomp 1993).

Assumptions about the educational benefits of IT are not universal, however. *Silicon Snake Oil: Second Thoughts on the Information Highway* (Stoll 1995) represents one critique of claims about the social payoff of IT (including educational benefits). Scholar Larry Cuban (1994) has questioned the use of computers in classrooms, and journalist Todd Oppenheimer (1997) has described the opportunity costs of spending educational funds on IT.

The fundamental dilemma of IT-based education is that it has not been proven to be more cost-effective than other forms of instruction (Cuban 1994, Kulik and Kulik 1991, Rosenberg

1997). Although real IT learning benefits have been demonstrated, we do not know whether the magnitude of those benefits is sufficiently large to justify consuming substantial resources and actively displacing other school curricula and programs.

Others (e.g., Papert 1995) suggest that the question at stake is no longer whether technology can change education or whether this change is desirable. Technology is a major factor in changing the entire learning environment, and schools will need to change in fundamental ways to keep pace.

The budget issues and educational opportunity costs associated with IT are significant. In a report to the U.S. Advisory Committee on the National Information Infrastructure, McKinsey and Company (1995) estimated that about 1.3 percent of the national school budget is spent on instructional technology. Increasing the level of IT in K–12 public schools could require raising this spending to as much as 3.9 percent of the national school budget, depending on the degree of IT intensity desired.[3] Moreover, these figures do not include IT operational expenses or the cost of teacher training—a significant factor in the effectiveness of computer-based instruction (CBI) (McKinsey and Company 1995, PCAST 1997, Ryan 1991, OTA 1995). Because school districts are under increasing fiscal stress, expanding IT resources could mean cutting other important programs. Oppenheimer (1997) details sacrifices in art, music, physical education, vocational classes, and textbook purchases that have been made so that computers could be placed in the schools. The negative effects of these sacrifices on learning and job skills are not usually considered in the growing emphasis on CBI.

Uncertainty about the effect of information technology in the classroom is not surprising. Computers are powerful tools that can be used in many different ways in education. CBI is a broad category that includes computer-assisted instruction (typically drill-and-practice exercises or tutorial instruction), computer-managed instruction (in which the computer monitors student performance and progress and guides student use of instructional materials), and computer-enriched instruction (in which the computer functions as a problem-solving tool). Computers have a variety of potential uses in education: generic information handling, real-time data acquisition, simulations, multimedia, educational games, cognitive tools, intelligent tutors, construction environments, virtual communities, information access environments, information construction environments, and computer-aided instruction (Rubin 1996). Software (courseware) for inquiry-based learning[4] is the ultimate goal of most CBI advocates and the most cognitively demanding form of learning (Kulik and Kulik 1991, McKinsey and Company 1995, PCAST 1997). Given the diversity of applications, from drill and practice exercise to participating in global environmental projects, generalizing about the costs and benefits of computers in the classroom is difficult. (See sidebar, "Innovative Education Projects.")

Diffusion of IT in Education

Over the past 20 years, computers and other information technologies have been diffused widely in the U.S. K–12 educational system. One measure of IT in schools is the ratio of students to computers. In 1998 there were approximately six students per instructional computer in public schools. (See figure 9-14.) Medium-sized schools (300–999 students) and large schools (1,000 or more students) had less access to instructional computers per student than small schools (fewer than 300 students). Schools located in cities had more students per instructional computer than schools in the urban fringes, towns, and rural areas.

Another measure is the degree to which schools are connected to the Internet. Schools have been connecting to the Internet at a rapid rate. By 1998, 89 percent of public schools were connected to the Internet—up from 35 percent in 1994. Although schools with large numbers of students in poverty and large minority populations were much less likely to be connected to the Internet a few years ago, by 1998 most of these differences had decreased sharply (NCES 1999).

The percentage of instructional rooms with access to the Internet also has been growing. In 1998, 51 percent of instructional rooms in public schools were connected to the Internet—nearly double that of 1997. As one might expect, wealthier schools tend to be better connected to the Internet. Public schools with high minority enrollments are likely to have a smaller percentage of instructional rooms connected to the Internet. Similarly, public schools with more students eligible for free or reduced-price school lunch had fewer instructional rooms wired. There are also regional differences. Schools in the Northeast had a lower proportion of rooms connected to the Internet than schools in the Southeast, Central, and West regions.

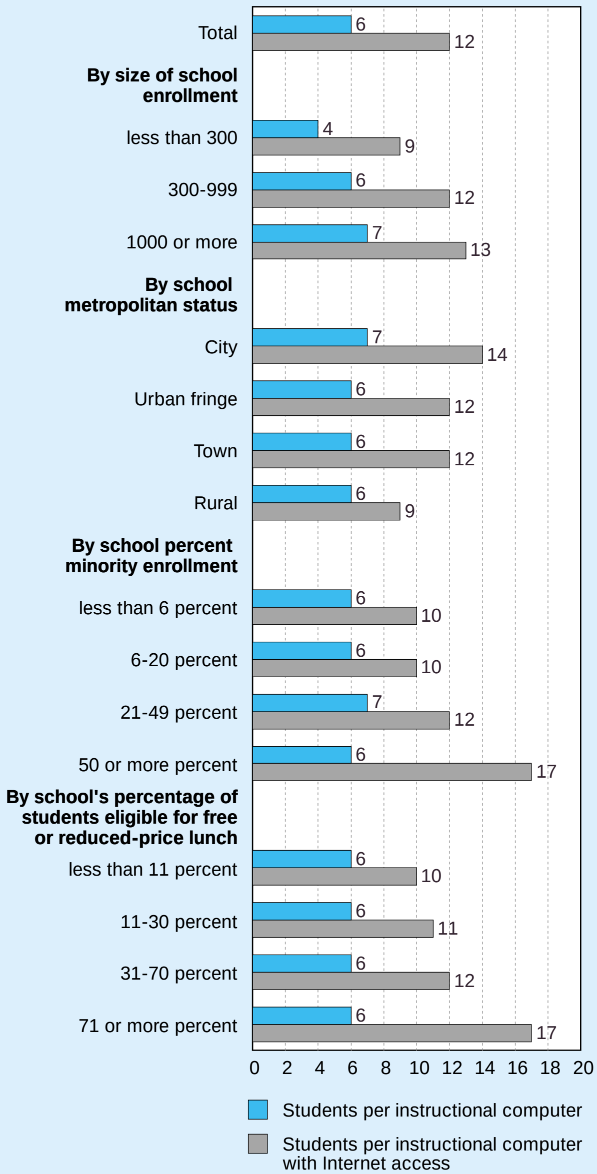
These differences do not appear to be permanent, however. Schools with high minority or subsidized lunch ratios were about as well connected to the Internet in 1998 as the most connected categories of schools were in 1997. (See appendix table 9-5.)

Schools are also upgrading their Internet connections. The percentage of schools using dial-up connections has dropped from 74 percent of public schools with Internet access in 1996 to 22 percent in 1998. (See figure 9-15.) The percentage of higher-speed connections using dedicated lines has increased from 39 percent in 1996 to 65 percent in 1998. The rapid increase in Internet connection reflects interventions through several programs to increase the use of IT in the schools. These initiatives include National Telecommunications and Information Administration programs to support novel application of information technology; NetDay volunteer efforts to connect schools and classrooms to the Internet; the e-rate pro-

[3]For example, ensuring adequate pupil-to-computer ratios and Internet connections to the school versus universal classroom deployment of full multimedia computers, Internet connections, and school networks. The McKinsey report details three alternative IT models and estimated costs.

[4]Inquiry-based learning represents active learning on the part of a student rather than passive assimilation of information that is "taught" by an instructor. Inquiry-based learning reflects active construction of models for conceptual understanding, the ability to connect knowledge to the world outside the classroom, self-reflection about one's own learning style, and a cultivated sense of curiosity. See Rubin (1996).

Figure 9-14.
Ratio of students per instructional computer and students per instructional computer with Internet access, by school characteristics: Fall 1998



SOURCES: U.S. Department of Education, National Center for Education Statistics, Fast Response Survey System, "Internet Access in Public Schools," NCES 98-031, and "Survey on Internet Access in U.S. Public Schools, Fall 1998," FRSS 69 (1998).

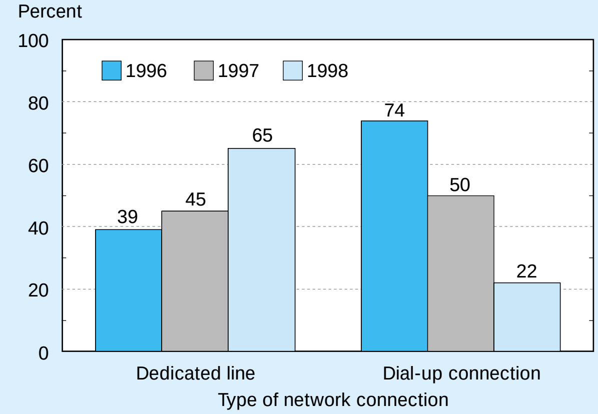
Science & Engineering Indicators – 2000

gram to subsidize telecommunication charges for schools; and many other programs by private corporations and foundations.

The Campus Computing Project (1998) has found that information technologies increasingly are being used in college courses as well. E-mail, the Internet, course Web pages, simulation, and other technologies are being used in more courses every year. (See figure 9-16.) In some cases, the decision to use more IT in college courses is largely left to the professor. On the other hand, universities such as UCLA have required professors to establish Web pages for each course and to put syllabuses online. As with IT in K–12 education, support for the increased use of IT in college campuses has not been universal. Many professors and administrators are enthusiastic early users of the new technologies; others prefer to wait for other institutions to find out which new technologies are useful in improving the quality of education.

Many of the new information technologies being used in scholarly communication and research can be used in education as well. Scientific and scholarly literature is increasingly available online, students can learn from computer modeling and simulation, and there are opportunities to participate in scientific experiments online. The types of IT that can be incorporated into education can be expected to expand.

Figure 9-15.
Percentage of public schools with Internet access, by type of Internet connection: Fall 1996–98



NOTE: Data were also collected for ISDN, cable modem, and wireless connections.

SOURCES: U.S. Department of Education, National Center for Education Statistics, Fast Response Survey System, "Advanced Telecommunications in Public Elementary and Secondary Schools, 1996," NCES 97-944, "Internet Access in Public Schools," NCES 98-031, and data from the "Survey on Internet Access in U.S. Public Schools, Fall 1998," FRSS 69, 1998.

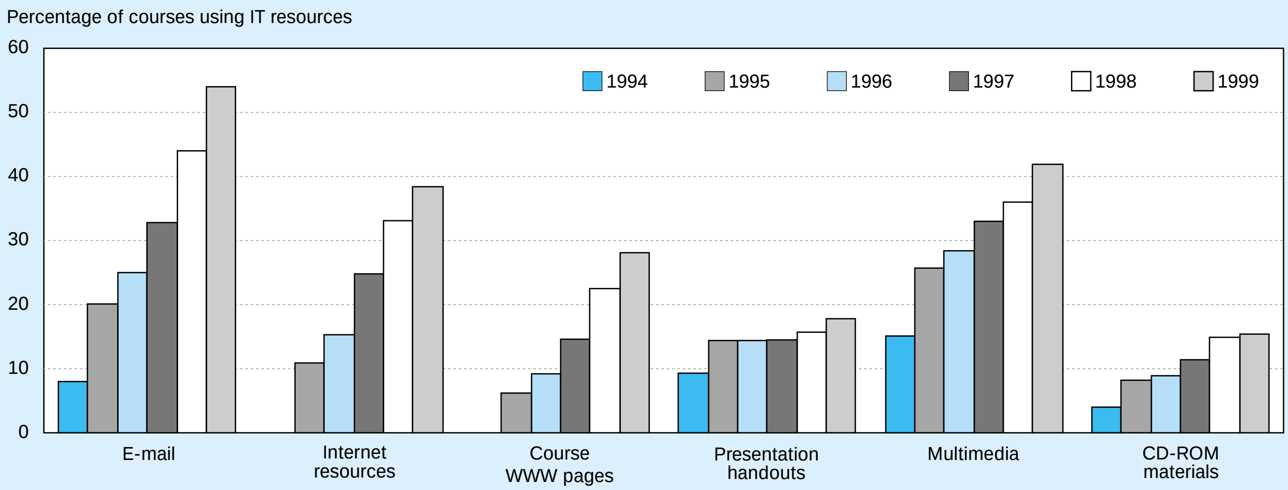
Science & Engineering Indicators – 2000

Effectiveness of IT in Education

As with the economic effects of IT, measuring the application of IT in education is much easier than measuring its effects or cost-effectiveness. Several factors explain why IT has not yet shown up in overall educational performance measures.

- ♦ There are measurement difficulties because people disagree on the appropriate ways to measure performance in education and the relevance of standardized test scores.
- ♦ It will take time for the educational system to figure out the best ways to use information technologies.

Figure 9-16.
Use of information technology in higher education instruction: 1994–99



SOURCE: Campus Computing Project (November 1999); and 1999 National Survey of Information Technology in Higher Education, available from <<http://www.campuscomputing.net/>>.

Science & Engineering Indicators – 2000

- ♦ Factors other than the technology itself, such as infrastructure support, school organization, and teacher training influence the effectiveness of the technology.
- ♦ The technologies are rapidly changing. The technologies that are available today—the Internet, multimedia and simulation software—are substantially different from those available even five years ago. Findings on the effectiveness of IT in the classroom from five years ago may be obsolete.

Many variables in the classroom influence the effectiveness of CBI in the classroom. Schofield (1995) found that the social organization of the school and classrooms affect computer-related learning, behavior, attitudes, and outcomes. Systematic understanding of the social and cognitive complexity of computer-based learning is limited. As the President's Committee of Advisors on Science and Technology (PCAST) Panel on Educational Technology noted:

> In 1995, less than 0.1 percent of our nation's expenditures for elementary and secondary education were invested to determine which educational techniques actually work, and to find ways to improve them (PCAST 1997).

A keyword search of the Educational Resources Information Center (ERIC) (http://www.accesseric.org/)—the primary bibliographic database used for educational research—yields thousands of citations related to computer-assisted instruction and student achievement. The notable characteristic of this research is its diversity: Studies range from anecdotal reports to formal experimental designs, many of which control for different sets of variables and include different types of computer use in different subject areas. Moreover, interest in the effects of computers on young people is not limited to learning and achievement. Concerns about the emotional and psychological effects of prolonged exposure to computing environments have also been raised.

Several syntheses and reviews of this literature have been carried out. Some are standard literature reviews, which can flexibly interpret the differences among studies but also may reflect the author's biases in selecting and interpreting studies. Other syntheses are "meta-analyses." Meta-analysis refers to the statistical analysis of the results of many studies to integrate the findings. Meta-analysis allows researchers to cumulate the findings of multiple studies into a single measure of outcome and estimate the magnitude of an independent variable's impact. A number of meta-analyses have been conducted on the effects of computer-based instruction.

Kulik and Kulik (1991) performed meta-analysis on 254 studies conducted between 1966 and 1986 that covered many different educational levels and instructional technologies. In a subset of this study, Kulik and Kulik analyzed 68 studies on computer-assisted instruction at the precollege level; they found that students using computer-based instruction scored (on average) in the 64th percentile on measures of learning and achievement, compared to the 50th percentile for students in a traditional class.

Ryan's (1991) meta-analysis of 40 studies[5] conducted between 1984 and 1989 found the average K–6 student using a microcomputer as an instructional tool performed in the 62nd percentile on tests, compared to the 50th percentile for the average K–6 student who did not use a microcomputer. Ryan

[5]Ryan also had a precise set of stringent selection criteria, including requirements that the study reflect experimental or quasi-experimental design, that the sample size be at least 40 students (a minimum of 20 students in the treatment and control groups), and that the treatment last eight weeks or longer.

also evaluated several sets of variables other than CBI that may have had an impact on the size of the effect. Of these variables, only the degree of teacher pretraining was statistically significant. In experimental groups in which teachers had fewer than 10 hours of computer pretraining, the effect size of CBI was negligible and, in some instances, negative. In groups in which teacher pretraining exceeded 10 hours, students in the experimental group performed at the equivalent of the 70th percentile—equivalent to a gain of half a school year gain over the control. These findings reinforce those of other studies that identify the crucial role of teacher preparedness in effective CBI (PCAST 1997; OTA 1995).

Schacter (1999) reviewed seven studies of educational technology:

- a meta-analysis of more than 500 studies (Kulik 1999);
- a review of 219 research studies from 1990 to 1997 (Sivin-Kachala 1998);
- an evaluation of the Apple Classrooms of Tomorrow (Baker, Gearhart, and Herman 1994);
- a study of West Virginia's Basic Skills/Computer Education statewide program (Mann et al. 1999);
- a national study of the effects of simulation and higher order thinking technologies on math achievement (Wenglinsky 1998);
- work on collaborative computer application in schools (Scardamalia and Bereiter 1996); and
- the work of the learning and epistemology group at MIT (Harel 1990; Harel and Papert 1991).

Collectively, these studies cover more than 700 empirical research studies and focus on the most recent work. On the basis of this review, Schacter (1999) concludes that "students with access to: (a) computer-assisted instruction or (b) integrated learning systems technology or (c) simulations and software that teach higher-order thinking or (d) collaborative networked technologies or (e) design and programming technologies show positive gains in achievements on research constructed tests, standardized tests, and national tests." Schacter also found evidence, however, that learning technology is less effective or ineffective when learning objectives are unclear and the purpose of the technology is unfocused.

Innovative Education Projects

Several special projects merit note. The Higher Order Thinking Skills (HOTS) Program, for example, is an intervention program for economically disadvantaged students in the fourth through seventh grades. Students were taken from their traditional classrooms and taught through an innovative curriculum that integrated computer-assisted instruction, drama, and the Socratic method. Students in the HOTS Program outperformed other disadvantaged students in a control group on all measures and had double the national average gains on standardized tests in reading and mathematics (Costa and Liebmann 1997).

The Buddy Project in Indiana, in which students in some classrooms were given home computers, also reported highly positive results across a variety of skills. Similar results were reported for the Computers Helping Instruction and Learning Development (CHILD) program in Florida, an elementary school program that emphasized student empowerment, teacher training and teamwork, and independent learning (ETS 1997). These studies suggest that the use of computers in enriched, nontraditional learning environments might achieve the fundamental changes in student learning that advocates of computer-based instruction desire.

Another innovative IT-based program is the Global Learning and Observations to Benefit the Environment (GLOBE) program (<<http://www.globe.gov/>>)—a worldwide network of students, teachers, and scientists working together to study and understand the global environment. Students and teachers from more than 7,000 schools in more than 80 countries are working with research scientists to learn more about our planet. GLOBE students make environmental observations at or near their schools and report their data through the Internet. Scientists use GLOBE data in their research and provide feedback to students to enrich their science education. Global images based on GLOBE student data are displayed on the World Wide Web, enabling students and other visitors to visualize the student environmental observations.

Distance Education

Distance education is not new. An estimated 100 million Americans have taken distance study—mostly correspondence courses—since 1890 (Distance Education and Training Council 1999), and in the 1960s there was widespread optimism about the use of television in education. Information technologies are providing significant new tools for distance education. Many schools are establishing distance education programs for the first time or expanding their existing distance education courses.

In online distance courses, students are likely to use e-mail to communicate with instructors and fellow students. The instructor typically sends "lectures" via e-mail or posts them on a Web page, and students submit assignments and have "discussions" via e-mail. Courses often supplement textbooks with Web-based readings. These courses may also meet in a chat room at a certain time for online discussions. Classes may also have online bulletin boards or Web conferences in which people ask and respond to questions over time. In the not-too-distant future, as Internet bandwidth increases, video lectures and videoconferencing will become more common additions to the online courses. Some classes may also use more elaborate systems called MUD/MOOs[6] for group interaction as well as many groupware programs that often involve simultaneous viewing of graphics and use of a shared writing space (i.e., electronic white board) (Kearsley 1997). Other classes may make use of computer simulations over the Internet.

Distance education offers several potential advantages. It may allow students to take courses not available in their geographical area, and it may allow students to take courses in a way that fits in with their career and family life. It makes education more available to working students with Internet access—especially older, mid-career students and those who have family responsibilities. For universities, it offers a way to expand enrollment without increasing the size of their physical plant.

Although distance education traditionally is regarded as education or training courses delivered to remote locations, distance education techniques—especially online education—can be incorporated as part of on-campus instruction as well. Universities are finding that significant numbers of on-campus students will take distance education courses when such courses are offered. At the University of Colorado at Denver, for example, more than 500 of 609 students enrolled in distance-education courses were also enrolled in regular courses (Guernsey 1998). Online courses can be more convenient for on-campus students, allowing them to better fit courses into their schedules. Such courses can also allow professors to augment course material with Web-based materials or guest lecturers in remote sites.

Trends in Distance Education

- ♦ The National Center for Education Statistics has conducted two surveys of distance education in post-secondary education institutions, the first in the fall of 1995 and the second in 1997/98 (NCES 1999b). The first survey covered only higher education institutions, while the second survey covered all post-secondary educational institutions. These surveys document that distance education is now a common feature of many higher education institutions and is growing rapidly. The majority of courses are at the undergraduate level and are broadly distributed across academic subjects.

- ♦ The number of higher education institutions offering distance education is growing. In the fall of 1995, 33 percent of 2-year and 4-year higher education institutions offered distance education courses. By 1997/98, the figure had grown to 44 percent. (See appendix table 9-6.) In 1995, 62 percent of public 4-year institutions offered distance education; by 1997/1998, 79 percent offered distance education. Private 4-year colleges are much less likely to offer distance education, but are also increasing their use of it. The percentage of private 4-year colleges offering distance education increased from 12 percent in 1995 to 22 percent in 1997/98.

- ♦ Distance education course and enrollments are growing more rapidly than the number of institutions offering distance education. The number of courses offered in 2-year and 4-year higher education institutions doubled from 25,730 in 1994/95 to 52,270 in 1997/98. (See appendix table 9-7.) The increases were fairly similar across all categories of higher education institutions (2-year and 4-year schools, public and private institutions, and all size categories). Course enrollments were also up sharply, more than doubling from 753,640 in 1994/95 to 1,632,350 in 1997/98 (NCES 1999b).

- ♦ Of those higher education institutions that offer distance education, the percentage that offer degrees that can be completed exclusively with distance education courses has remained essentially constant, 22 percent in 1997/98 compared to 23 percent in 1995 (NCES 1999b).

- ♦ There has been a significant change in the technologies used for distance education. (See appendix table 9-8.) In 1995, the most widely used technologies were two-way interactive video (57 percent) and one-way prerecorded video (52 percent). These were still widely used in 1997/98 at 56 percent and 48 percent, respectively. Internet-based courses, however, expanded greatly. The percentage of institutions offering Internet courses using asynchronous (not requiring student participation at any set time of day or week) computer-based instruction was 60 percent in 1997/98. The percentage of institutions that offered Internet courses using synchronous (real-time) computer-based instruction was 19 percent in 1997/98 (NCES 1999b).

Significance of Distance Education

Despite substantial and growing experience with online education, there have been relatively few thorough assessments. Frank Mayadas of the Sloan Foundation (which supports asynchronous learning[7]) suggests that because online education provides access to education to a new student population, it does not need to be directly compared to on-campus education (Miller, n.d.). Instead, asynchronous learning should be assessed according to degree of access provided, the extent to which learning meets or exceed goals set by faculty and the institution, the extent to which it is a satisfying experience for faculty, its cost-effectiveness, and its student satisfaction.

There is evidence that, at least in some circumstances, online education can be very effective. The rapid growth and success of some online education providers suggests that they are providing acceptable learning experiences. At the same time, there are many other case studies that report at least initial frustrating experiences with online education.

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[6]MUD stands for "multiple user dimension, dialogue, or dungeon." MOO stands for "MUD, object oriented."

[7]Asynchronous learning refers to distance learning that uses technologies that allow participants to interact without having to be available at the same time.

Kearsley, Lynch, and Wizer (1995) reviewed the literature that examines the use of computer conferencing in higher education and found that, in comparison with traditional classes, student satisfaction with online courses is higher, measures of student achievement are the same or better, and there is usually more discussion among students and instructors in a course.

Schutte (1997) reported on an experiment carried out during a fall 1996 social statistics course at California State University, Northridge, in which students were randomly divided into two groups—one taught in a traditional classroom and the other taught virtually on the World Wide Web. Text, lectures, and exams were standardized between the two groups. Schutte found that, contrary to expectations, the virtual class scored an average of 20 percent higher than the traditional class on both examinations.

At the same time, distance education raises issues concerning broader effects on the university. Although online education may expand the pool of people who have access to education, it also may take students away from traditional education, and some scholars express concern that it will undermine the traditional college experience. Some people question whether the quality of distance education can match that of face-to-face instruction. Moreover, creating the kind of intellectual or social community that characterize colleges may be much harder through distance learning.

Distance education also brings universities into competition with each other in a new way. Because distance education courses are available to anyone, anywhere, they allow universities to compete for students in other geographic areas. Top-tier universities such as Stanford and Duke are beginning to market Internet-based master's degrees to national audiences. New distance education–based universities—such as Jones International University (<<http://www.jonesinternational.edu>>), the first online-only university to gain accreditation; the University of Phoenix online (<<http://online.uophx.edu>>); and the Western Governors University (<<http://www.wgu.edu>>)—are also marketing courses that compete with universities and community colleges that have in the past been providers of continuing education services in their region. Others see opportunities to market American university degrees to large potential student populations abroad. The reverse is also happening. The United Kingdom's Open University, which has established a good reputation as a provider of distance education in the U.K. since 1971, has started an operation in the United States (Blumenstyk 1999a).

In addition, distance education is creating new markets for companies selling course materials and software to assist in online courses (Blumenstyk 1999b). Publishers such as McGraw-Hill and software companies such as Microsoft and Oracle have developed and are marketing online courses (Morris 1999).

Some people regard distance education technologies as providing new tools to professors. Others foresee mass production education, in which packaged multimedia courses will reduce the importance of professors (Noble 1998). As one indicator of concern, more than 850 faculty members at the University of Washington signed a letter to Governor Gary Locke protesting the state's plans for investing in information technology (Monaghan 1998). The expanding and potentially lucrative new market for online course materials has also raised the issue of whether professors or the university should own the intellectual property embodied in online courses. The American Association of University Professors (AAUP) has taken the position that professors rather than institutions should retain primary property rights for online course materials (Schneider 1999) and has questioned the accreditation of Jones International University (Olsen 1999).

The issues raised by IT in education are still in their infancy and will probably take years to resolve.

IT, Research, and Knowledge Creation

Information technology is having broad and substantial effects on research and the creation of knowledge. IT facilitates:

- ♦ new ways of communicating and storing scholarly information;
- ♦ new methods of research and new fields of science; and
- ♦ new forms of scientific collaboration.

The effects of IT on research and knowledge creation are important for two reasons. First, they have significant effects on the research community, which in turn affects innovation and education in society. Second, many applications of IT that have been used first in the research community, such as e-mail and the World Wide Web, have later diffused more widely and have had major effects outside of the research community.

Scholarly Communication

In his 1945 *Atlantic Monthly* article, Vannevar Bush illustrated how helpful it would be to researchers to have access at their desk to the great body of the world's knowledge. In the past few years, that vision has come much closer to reality. The Internet and the World Wide Web, originally developed as tools for scientific communication, have become increasingly powerful. An increasing amount of scholarly information is stored in electronic forms and is available through digital media—primarily the World Wide Web.

Scholars derive many advantages from having scholarly information in digital form. They can find information they want more easily using search tools. They can get the information without leaving their desks, and they do not have to worry about journals being missing from the library. They can get more complete information because electronic publications are not constrained by page limits as printed journals commonly are. Multimedia presentations and software can be combined with text, enriching the information and facilitating further work with it. Additional references, comments from other readers, or communication with the author can be a mouse-click away.

There are also advantages for libraries. Many patrons can access the same electronic information at the same time, possibly without having to visit the library facility; electronic archives do not take up the space held by old journal collections; and libraries can stretch limited financial resources, especially for accessions. All of these factors exert strong pressures for making scholarly information available electronically.

The traditional system of printed academic journals, however, performs functions other than information transmission. Journals organize articles by field and manage peer review processes that help to screen out bad data and research. Scholars achieve recognition through publication in prestigious journals, and universities base hiring and promotion decisions on publication records. Similarly, traditional libraries have played roles in scholarship that go beyond storing books and journals. The library is a place for students and scholars to congregate, and it often has been the intellectual center of a university.

Electronic publications also raise issues about the archiving of information. Rapidly changing IT means that publications stored in one format may not be readily accessible to future users. This problem may become increasingly difficult when electronic "publications" include hyperlinks, multimedia presentations, or software programs.

There are several different ways to put scholarly information online, all of which are expanding. These "media" include individual Web pages, preprint servers, electronic journals, and electronic versions of print journals.

Many scholars put their own work on personal or research-group Web pages. These sites may include "reprints" of published material, preprints, working papers, talks and other unpublished material, bibliographies, data sets, related course material, and other information of use to other scholars. This approach provides an efficient way for scholars to respond to requests for information from colleagues or students.

Another rapidly growing form of electronic publication has been preprint or reprint servers, whereby authors in a specified field post their articles. These servers enable readers to find papers of interest, accelerate dissemination of new knowledge, and provide a focal point for information in a field. The original and most widely copied preprint server is the Los Alamos physics preprint server (<<http://xxx.lanl.gov/>>). This site was started in 1991 by Los Alamos physicist Paul Ginsparg as a service to a small subfield of physics; it has grown to cover many fields of physics, astronomy, mathematics, and computation. By mid-1999 it was receiving more than 2,000 new submissions each month and had close to 100,000 connections each day (e.g., for searching, reading, or downloading papers) from approximately 8,000 different hosts. (See figures 9-17 and 9-18.) It has become the main mode of communication in some fields of physics. Fourteen other places around the globe have established mirror sites that copy the information on the Los Alamos server to provide alternative access to the information. One effect of the server is that physicists around the world who do not have access to major research libraries can keep abreast of the latest developments in physics.

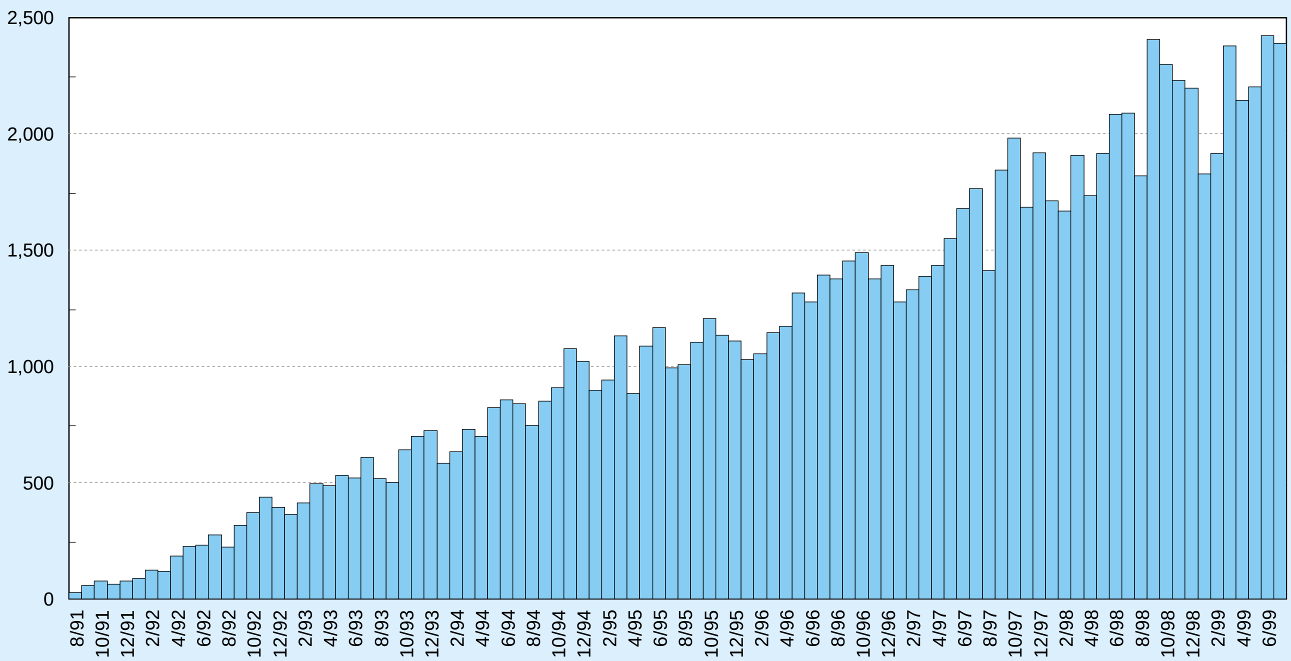
The preprint server is a very efficient mode of communication. Odlyzko (1997) estimates that the Los Alamos server costs \$5–\$75 per article (the upper estimate is based on deliberately inflated assumptions about costs), compared to costs of \$2,000–\$4,000 per article for an average scholarly print journal. The server does not provide refereeing of articles, but it does provide a means for scientists to comment on papers that are posted as well as to respond to the comments of others. It also provides a forum for electronic discussions in various fields. The Los Alamos server is frequently regarded as a model. Other preprint servers modeled after the Los Alamos server include the Economics Working Paper Archive hosted by the Economics Department of Washington University (<<http://econwpa.wustl.edu/wpawelcome.html>>) and a Chemical Physics Preprint Database operated by the Department of Chemistry at Brown University and the Theoretical Chemistry and Molecular Physics Group at the Los Alamos National Laboratory (<<http://www.chem.brown.edu/chem-ph.html>>). As other preprint servers develop, it will become easier to understand how much the Los Alamos success derives from the particular nature of the research and researchers in physics and how much can be generalized.

Implementation issues associated with scholarly electronic publishing were underscored by the 1999 proposal by NIH director Harold Varmus for a Web-based repository of biomedical literature to be hosted by NIH originally called E-biomed (Varmus 1999). In the original proposal, this repository was intended to be a preprint server, modeled after the Los Alamos server; that proposal was revised, however, after extensive public comment and discussion in the press. Some people expressed concern that unrefereed medical publications might be a public health risk. Others suggested that NIH, as the funding agency for biomedical research, should not itself publish research results. Much of the criticism came from professional societies and the publishers of academic journals, who regarded E-biomed as a threat to their circulation and revenue. In response to these comments, NIH revised the proposal to create a "reprint" server that would work with existing journals to post the text of those journals after they are published. (NIH also changed the name, first to E-biosci, and then to PubMed Central.) Although this proposal is less threatening to publishers, the benefits to them of participation are not yet clear (Marshall 1999).

The controversy over the Varmus proposal shows that key players include not only researchers and publishers but also the broader public that may access electronic publication. Research posted on the Web that has direct public health or policy implications is likely to receive more scrutiny than research with a primarily scientific audience. As regulatory attention to health information on Web sites illustrates, the quality of some kinds of information may trigger more concern—and intervention—than others.

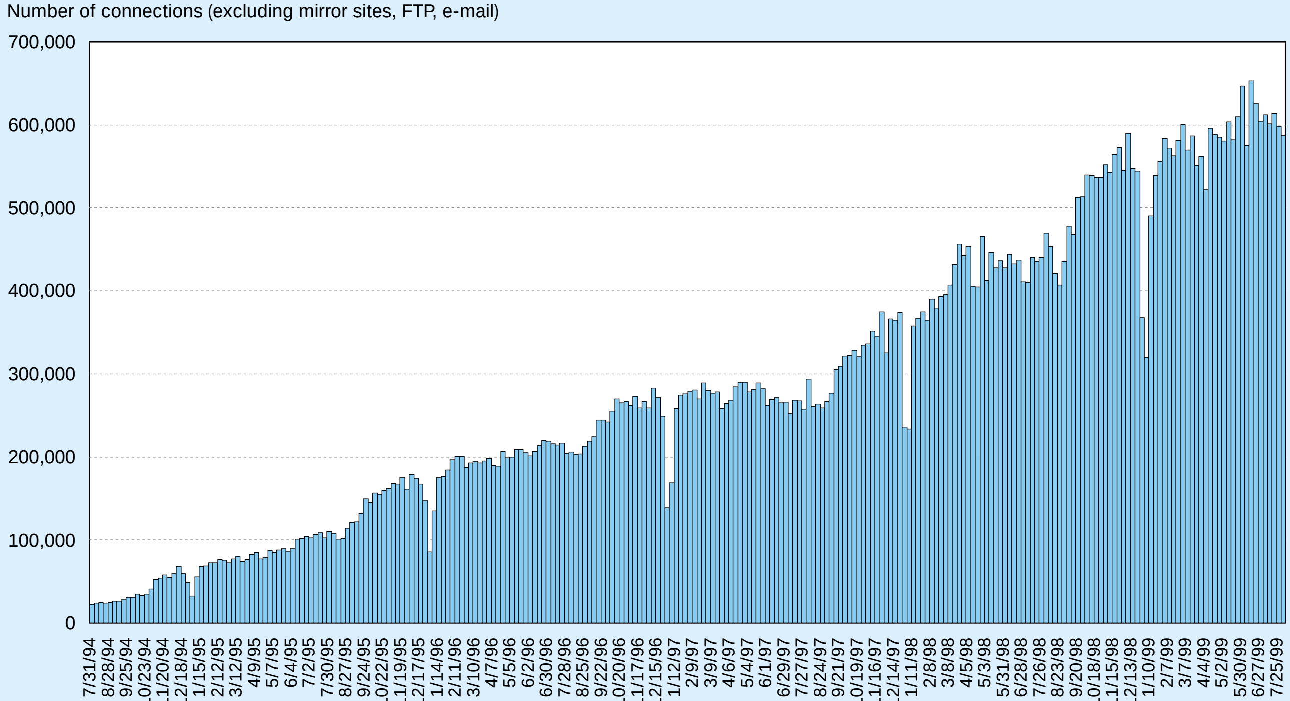
Electronic journals have also been expanding rapidly. The Association of Research Libraries' (ARL) 1997 directory of electronic journals, newsletters, and academic discussion lists included 3,400 serial titles—twice as many as in 1996. Of

Figure 9-17.
Number of new submissions received at Los Alamos preprint server each month since August 1991



SOURCE: Los Alamos preprint server available from <<http://xxx.lanl.gov/>>. *Science & Engineering Indicators – 2000*

Figure 9-18.
Number of connections each week at Los Alamos preprint server: 7/31/94–8/1/99

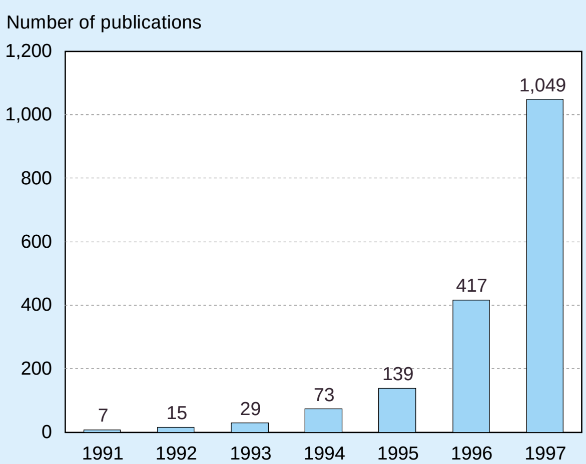


SOURCE: Los Alamos preprint server available from <<http://xxx.lanl.gov/>>. *Science & Engineering Indicators – 2000* that total, 1,465 titles were categorized as electronic journals; of these, 1,002 were peer-reviewed, and 708 charge in some manner for access. The number of peer-reviewed electronic publications (which includes some publications not classified as journals) has increased rapidly since 1991. (See figure 9-19.) The 1999 ARL directory is expected to list more than 3,000 peer-reviewed titles (Mogge 1999). The increase reflects the fact that traditional print publishers are moving to make their titles available electronically—both as electronic versions of their paper products and as electronic supplements or replacements for the print journal.

Electronic journals can be offered either directly by publishers or through intermediary services that aggregate the titles from many publishers in one service (Machovec 1997). Publishers are currently experimenting with different ways of pricing electronic journals. Some provide separate subscriptions for electronic versions that may be higher or lower cost than the print version. Others provide the electronic version at no charge with a subscription to the print version. Some publishers offer free online access to selected articles from the print version and regard the online version as advertising for the print version (Machovec 1997). Publishers of fee-based electronic journals generally protect their information from unauthorized access by restricting access to certain Internet domains (such as those of universities that have acquired a site license) or through passwords.

Print publishers who move to electronic publishing have found that their costs remain significant (Getz 1997). A large proportion of the cost of most journals covers editing and refereeing of manuscripts and general administration—which, at least initially, remains about the same for electronic journals. In addition, there are costs associated with new information technology and with formatting manuscripts for electronic publication. Some of these costs might decline with time, experience, and improved technology.

Figure 9-19.
Peer-reviewed electronic publications



SOURCE: Mogge, D., *ARL Directory of Electronic Journals, Newsletters and Academic Discussion* (1997): Foreward. Available from <<http://www.arl.org:591/foreword.html>>.

Science & Engineering Indicators – 2000

Electronic publication also can affect the revenue stream of print publishers. If a publisher provides a site license for a university library that enables anyone on campus to read the journal, individual subscriptions may decline. Moreover, electronic journals may be less attractive to advertisers than print versions.

Some electronic-only journals—generally run by an unpaid editor and distributed on the Internet at no cost to the user—are operated at low cost. They can provide a similar filtering function to that of print journals (using, as do other scholarly journals, unpaid reviewers), but they generally have lower administrative and publishing costs. Many free journals are subsidized, directly or indirectly, by another organization; some charge authors fees for articles that are printed to cover their costs. Odlyzko (1997) estimates that these journals can operate at $250–$1,000 per article (again, compared to $2,000–$4,000 per article for average academic publications).

The system of scholarly communication is changing rapidly, but the direction of that change remains uncertain. Although scholars want to be able to access information in electronic form, and the costs of electronic publishing can be lower, there are some barriers to electronic publishing. Scholars, who do not directly bear the cost of journals, tend to submit their articles to print journals rather than electronic journals because they still regard print journals as more prestigious (Kiernan 1999). (They may also post their articles on the Web for convenience.) Research libraries, which are under pressure to cut journal costs, also must continue to meet the needs of their research communities to provide access to the most important journals (which are mostly still print journals), and libraries have trouble affording print and electronic versions of the same journals. Libraries are seeking new strategies, such as negotiating university-system wide packages for electronic journals to lower costs (Biemiller 1999) or even supporting new, lower cost journals to compete with high-cost journals (ARL 1999).

Digital Libraries

The term "digital library" does not refer to a library in the conventional sense of a central repository of information. Rather, the term encompasses a broad range of methods of storing materials in electronic format and manipulating large collections of those materials effectively. Some digital library projects focus on digitizing perishable or fragile photographs, artwork, documents, recordings, films, and artifacts to preserve their record and allow people to view items that could otherwise not be displayed publicly. Others are digital museums, which allow millions of individuals access to history and culture they would not otherwise have.

One example is JSTOR, an Andrew W. Mellon Foundation-funded project to convert the back issues of paper journals into electronic formats (JSTOR 1999). The goals of this project are to save space in libraries, to improve access to journal content, and to solve preservation problems associated with storing paper volumes. High-resolution (600 dpi) bit-mapped images of each page are linked to a text file generated with optical character recognition software to enable searching. JSTOR does not publish current issues of the journals, which would put journal publishers' revenue stream at risk; instead, it publishes volumes when they are either three or five years old, depending on the journal. JSTOR now covers more than 117 key journal titles in 15 disciplines. Access to JSTOR is available through institutions such as university libraries that have site licenses.

The Federal Government's multi-agency Digital Library Initiative (<<http://www.dli2.nsf.gov/>>) is supporting projects at many universities around the country. These projects are designed to improve methods of collecting, storing, and organizing information in digital forms and to make information available for searching, retrieval, and processing via communication networks. These projects cover a broad range of topics in the sciences, social sciences, arts, and humanities. They cover information creation, access and use, and archiving and preservation for information as diverse as maps, videos, scientific simulations, and medical records. That diversity enriches the IT through these projects and the clientele for electronic information. It also differentiates digital library projects from preprint servers. The sidebar "Growth of the World Wide Web" provides additional information on libraries and the Web.

Effects of IT on Research

IT has had a major effect on research. It has facilitated new methods of research and development, new forms of research collaboration, and new fields of science. Computers have affected research from their beginnings, and scientific users historically have had the most advanced computing capability. Today, advances in the underlying technology make relatively advanced capabilities available more broadly, fueling the diffusion of IT from its historical stronghold in the physical sciences across the research community through other natural sciences, engineering, social sciences, and the humanities.

New Research Methods

High-end computing and software have had a fundamental impact on research in many areas of science and technology. Some areas of research—such as high-energy physics, fluid dynamics, aeronautical engineering, and atmospheric sciences—have long relied on high-end computing. The ability to collect, manipulate, and share massive amounts of data has long been essential in areas such as astronomy and geosphere and biosphere studies (Committee on Issues in the Transborder Flow of Scientific Data 1997). As information technologies have become increasingly powerful, they have facilitated continued advances in these areas of science and become increasingly vital to sciences such as biology that historically used IT less extensively.

Shared databases have become important resources in many fields of science and social sciences. Examples include Census Bureau databases, data from large scientific instruments such as the Hubble Space Telescope, genetic and protein databases (e.g., GenBank), and the NIH-funded human brain project, as well as many smaller and more specialized databases. These databases allow researchers working on different pieces of large problems to contribute to and benefit from the work of other researchers and shared resources.

Modeling and simulation have become powerful complements to theory and experimentation in advancing knowledge in many areas of science. Simulations allow researchers to run virtual experiments that, for either physical or practical reasons, they cannot run in reality. As computer power grows, simulations can be made more complex, and new classes of problems can be realistically simulated. Simulation is contributing to major advances in weather and climate prediction, computational biology, plasma science, high-energy physics, cosmology, materials research, and combustion, among other areas. Industry also uses simulations extensively to test the crashworthiness of cars and the flight performance of aircraft (DOE/NSF 1998) and to develop new financial instruments (e.g., derivatives).

The performance of computers continues to improve at a rapid rate. The Department of Energy's Accelerated Strategic Computing Initiative program, which uses simulation to replace nuclear tests, deployed the first trillion-operations-per-second (teraops) computer in December 1996 and is planning to operate a 100 teraops computer by 2004 (National Science and Technology Council 1999). Researchers funded by DARPA, NASA, and the National Security Agency (NSA) are evaluating the feasibility of constructing a computing system capable of a sustained rate of 10^{15} floating point operations per second (1 petaflop).

IT in Biology

IT is becoming increasingly important in biology. Genomics research, including efforts to completely map the human genome (which consists of 3 billion nucleotide base pairs) by 2005, depends on robots to process samples and computers to manage, store, compare, and retrieve the data (Varmus 1998). The databases that contain gene and protein sequence information have been growing at an enormous rate. GenBank, NIH's annotated collection of all publicly available DNA sequences, has been growing at an exponential rate: The number of nucleotide base pairs in its database has been doubling approximately every 14 months. As of August 1999, GenBank contained approximately 3. 4 billion base pairs, from 4.6 million sequence records. These base pairs were from 50,000 species; *Homo sapiens* accounted for 1.8 billion of the base pairs. (See figure 9-21.)

GenBank is part of a global collaboration; it exchanges data daily with European and Japanese gene banks. In addition to the publicly available sequences in GenBank, private companies are rapidly developing propriety genetic sequences.

To make use of data from the human genome project, new computational tools are needed to determine the three-dimensional atomic structure and dynamic behavior of gene products, as well as to dissect the roles of individual genes

Growth of the World Wide Web

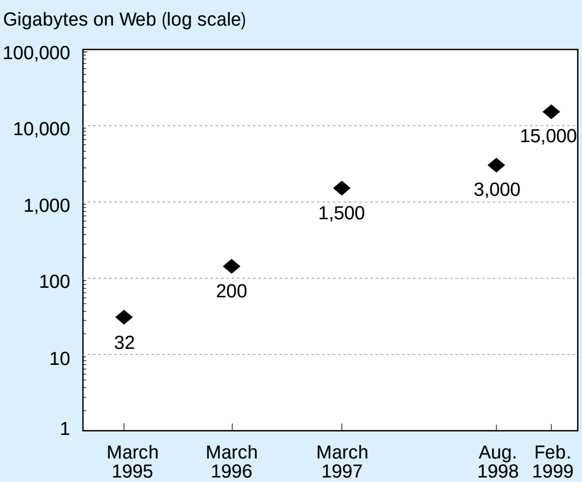
One indicator of the growth of digital information is the growth of the World Wide Web. The volume of information on the Web has grown enormously. (See figure 9-20.) Although scholarly information is only a small part of the Web, the amount of useful scholarly information is still large.

Lesk (1997a) notes that a book such as *Moby Dick* is approximately 1 megabyte in plain-text ASCII form, so 1 terabyte is the equivalent of 1 million substantial books. By this measure, the amount of text on the Web as of February 1999 was equivalent to 6 million books.

Lawrence and Giles (1999) estimate that there were 800 million pages on the publicly indexable Web as of February 1999—corresponding to 15 terabytes in HTML or 6 terabytes in text.* They also estimated that 3 terabytes of image data were available online. They found that about 6 percent of Web servers have scientific or educational content—defined as university, college, or research lab servers.

In addition to the World Wide Web, other online information providers such as Dialog and Lexis-Nexis make large amounts of information available. Dialog has approximately 9.2 terabytes and Lexis-Nexis has approximately 5.9 terabytes (Lesk 1997a). Many universities now have access to Lexis-Nexis (Young 1998).

Figure 9-20.
Growth in number of gigabytes on the Web



NOTE: The larger jump from 1998 to 1999 may be because Alexa counted actual pages it found and retrieved, whereas Lawrence and Giles used a sampling technique.

SOURCES: 1996, 1997, and 1998 data from Alexa <<www.alexa.com/company/inthenews/webfacts.html>>; 1999 data from Lawrence, S., and L. Giles, "Accessibiility of Information on the Web," *Nature* 400 (July 8): 107–109.

Science & Engineering Indicators – 2000

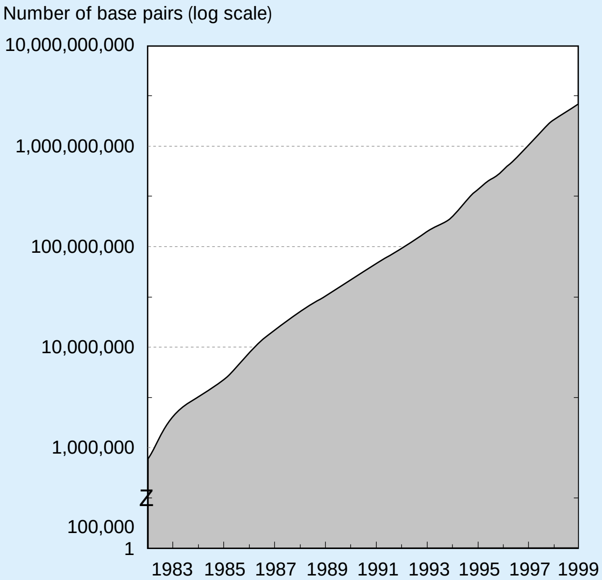
By comparison, the largest library in the world, the Library of Congress, has 17 million books—equivalent to 17 terabytes of text. The Library of Congress also has 2 million recordings, 12 million photographs, 4 million maps, 500,000 films, and 50 million manuscripts. In all, it has 115 million items (Library of Congress 1999). Because these other types of collection would be very large in digital form, the collections in the Library of Congress might total 3,000 terabytes (Lesk 1997a).

Thus, the amount of information in network-accessible digital form is already very large and is approaching the volume of text in the largest libraries. It already exceeds the volume of text in libraries that are readily accessible to most people. It does not yet, however, match the total holdings of the largest libraries in sheer volume. On the other hand, the range of information available online is broader than that in most libraries, albeit in ways that do not necessarily make it more useful—as typical results of Web searches illustrate today. The amount of information available online is growing quickly and will likely grow even faster as more people obtain higher-bandwidth Internet connections and can more readily use the Internet for music, video, and multimedia information that they generate as well as consume.

Of course, there are great qualitative differences between material in libraries and material on the Web. Most material in libraries has been judged by editors and librarians to have some lasting value—it has been selected. Much of the material on the Web has not gone through such filters and has been generated for a wider variety of purposes (e.g., public relations or commercial information). In addition, for most of the material on the Web, there is no guarantee that the information will be accessible in the future. On the other hand, the Web is useful as a source for materials such as preprints and technical reports that may be difficult to find in libraries.

*Lawrence and Giles tested 3.6 million random Internet Protocol (IP) addresses to see if there was a server at that address. They found one server for every 269 requests. Because there are 4.3 billion possible IP addresses, this result led to an estimate of 16 million Web servers. After eliminating servers that were not publicly indexable (such as those behind firewalls or those with no content), they estimated the publicly indexable Web to comprise 2.8 million servers. Lawrence and Giles sampled 2,500 of these servers at random and found the average number of pages per server to be 289, leading to an estimate of 800 million Web pages. These pages averaged 18.7 kilobytes (7.3 kilobytes of text after HTML tags were removed). Lawrence and Giles also found 62.8 images per server, with a mean size of 15.2 kilobytes. Using a similar sampling method, the Online Computer Library Center (OCLC 1999) estimated that there were 288 million (± 35 percent) unique, publicly accessible Web pages in June 1999.

Figure 9-21.
Growth of Genbank



SOURCE: Genetic Sequence Data Bank, NCBI-GenBank Flat File Release 113.0 (15 August 1999): Distribution Release Notes. Available from <<ftp://ncbi.nlm.nih.gov/genbank/gbrel.txt>>.

Science & Engineering Indicators – 2000

and the integrated function of thousands of genes. To model the folding of a protein—a capability that would dramatically aid the design of new drug therapies—takes the equivalent of months of Cray T3E computer time (DOE/NSF 1998). Researchers are also using pattern recognition and data mining software to help decipher the genetic information (Regalado 1999).

The importance of informatics for biology and medicine is difficult to overemphasize. Many scientists expect it to revolutionize biology in the coming decades, as scientists decode genetic information and figure out how it relates to the function of organisms. As NIH director Varmus (1999) stated, "All of biology is undergoing fundamental change as a result of new methods that permit the isolation, amplification, and detailed analysis of genes." Genomic information will be used to assess predisposition to disease, predict responses to environmental agents and drugs, design new medicines and vaccines, and detect infectious agents. New areas of biology—such as molecular epidemiology, functional genomics, and pharmacogenetics—rely on DNA data and benefit more generally from new, information-intensive approaches to research.

Research Collaboration

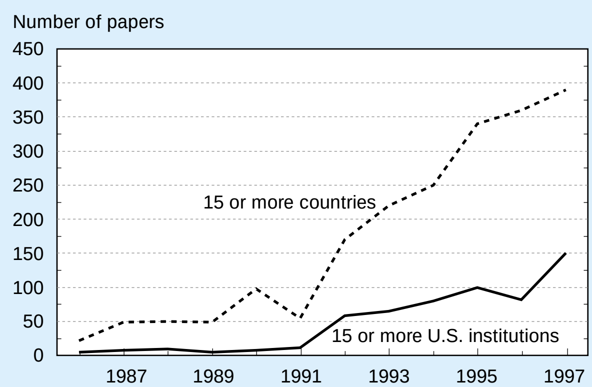
IT facilitates enhanced collaboration among scientists and engineers. E-mail, the World Wide Web, and digital libraries allow information to be accessed from anywhere and let geographically separated scientists (even if they are only a building away) work together better. Some companies with laboratories around the world pass off problems from one lab to another so researchers can work on the problems 24 hours a day.

Scientific collaboration—as measured by the increase in the percentage of papers with multiple authors—has been increasing steadily for decades. Much of this collaboration is probably the result of better telephone service and air travel, as well as the availability of fax machines and e-mail. Large-scale scientific collaborations may be especially enabled by new information technology. There has been a rapid increase in the number of papers with authors from many institutions that coincides with the rapid expansion of the Internet. (See figure 9-22.)

More advanced technologies to aid R&D collaboration are coming into use and are likely to migrate to broader usage in the next few years. (See sidebar, "Collaboratories.")

How the application of IT will affect the science and engineering enterprise in the long run is not clear. Although the potential for change is obvious, we do not know how much and what kind of change will endure. The availability of information from anywhere may reduce the need for researchers to be close to major research libraries. The ability to operate major scientific instruments over the Web may reduce the need for scientists to be located at major laboratories. If virtual laboratories can function effectively, there may be less need to assemble large multidisciplinary teams of scientists and engineers at a laboratory to work on complex problems at a common location. Most scientists, however, may still want extensive face-to-face interaction with their colleagues, and they may want hands-on participation in experiments.

Figure 9-22.
Number of papers with authors from 15 or more countries or 15 or more U.S. institutions: 1986–97



SOURCE: CHI Research, Inc.

Science & Engineering Indicators – 2000

Collaboratories

In 1989, William Wulf (now president of the National Academy of Engineering but then at the National Science Foundation) coined the term “collaboratory” to describe the concept of using information technologies to make geographically separate research units function as a single laboratory. Wulf defined a “collaboratory” as a “...‘center without walls’ in which the nation’s researchers can perform their research without regard to geographical location—interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries” (CSTB 1993).

In subsequent years, a number of programs began to develop tools for collaboratories and fund pilot projects. Among the earliest projects were:

- The NSF-sponsored Upper Atmosphere Research Collaboratory (UARC)—now the Space Physics and Aeronomy Research Collaboratory (SPARC)—which allows space physics researchers around the world to control and gather data from more than a dozen instruments located around and above the globe. SPARC is based at University of Michigan (<<http://www.crew.umich.edu/UARC/>>); it has collaborators from many institutions.
- The DOE-sponsored Materials MicroCharacterization Collaboratory (<<http://tpm.amc.anl.gov/MMC>>), which conducts research on the microstructure of advanced materials. This effort involves three DOE national laboratories, the National Institute for Standards and Technology (NIST), the University of Illinois, and several scientific instrument companies.
- The DOE-sponsored Diesel Combustion Collaboratory (<<http://www.collab.ca.sandia.gov/Diesel/ui/>>), which focuses on diesel engine emissions control and involves three DOE national laboratories, the University of Wisconsin, and several diesel engine manufacturers.

These collaboratories use a similar set of technologies for collaboration, including:

- Internet-based desktop video conferencing;
- Shared access to databases and computer simulation;
- Shared virtual workspaces, such as “white boards” on which researchers can sketch out ideas; and
- Shared electronic laboratory notebooks to capture the details of experiments.

One of the most important aspects of collaboratories is the ability to share scientific instruments over the Internet. This sharing may involve many users from different sites using a single major scientific instrument, such as a synchrotron at a national laboratory, or it may involve using a network of instruments, such as environmental sensors in geographically separate parts of the globe.

Many of the tools developed in these and other pilot projects are now being used in other research collaborations.*

Among the benefits of collaboratories (Ross-Flanigan 1998) are that:

- Scientists can avoid going to scientific instruments in remote locations.
- Many more universities, scientists, and students can participate in or observe experiments.
- By connecting computation to experiments, scientists can better and more quickly integrate experiments and theory. Theorists and experimentalists can work together in real time, greatly reducing the time required to analyze experiments.
- Scientists can put together quick video conferences to discuss the data.
- Students can participate in experimentation much earlier in their careers than before.

On the other hand, virtual communication has been found to be less successful than face-to-face communication in building trust between researchers. In addition, as a result of greater outside participation in the research, good researchers have more distractions. The early collaboratories also found that Internet congestion, the lack of reliability of some of the tools, and software changes slowed research.

*See, for example, <<http://www.si.umich.edu/research/projects.htm#collabor>>; <<http://www.mcs.anl.gov/DOE2000/pilot.html>>; <<http://doe2k.lbl.gov/doe2k/index.html>>.

IT and the Citizen

IT in the Home

The breadth of information technologies in the home is considerable, ranging from televisions and telephones to smart house technology, microprocessors in coffeepots, personal computers (PCs), and the Internet.[8] The trends and developments presented here focus only on home computers and Internet linkages,[9] not on the full spectrum of home informatics or ways in which people can access the Internet outside of the office (such as in libraries, kiosks, or Internet cafes). In addition, the analysis concentrates on social impacts that occur within the home itself, such as changes in individuals, in family dynamics, or in household operations.

[8]For a more extensive discussion of the diffusion and effects of information technologies in the home, see National Science Foundation, *The Applications and Implications of Information Technologies for the Home* (1999) (available at <<http://srsweb.nsf.gov/it_site/index.htm>>); National Technical Information Administration, *Falling Through the Net: Defining the Digital Divide* (1999) (available at <<http://www.ntia.doc.gov/ntiahome/digitaldivide/>>).

[9]Note that there is increasing diversity in technical access to the Internet—for example, through television (web TV™) and telephones. Such alternative mechanisms are not explicitly addressed in this study; most research reviewed here assumes that Internet access is achieved through a personal computer.

The broader social impacts of home-based computing—for example, on culture and values, democratic participation, and social cohesion—are not addressed; neither are the impacts of home-based businesses that are facilitated by PCs and Internet linkages.

Two distinct eras characterize the diffusion of home computing in the United States. The first era is reflected in the steady growth in home ownership of personal computers throughout the 1980s (PCs were introduced commercially in the late 1970s); the second era is reflected in the accelerating adoption of home PCs and Internet use that began about five years ago. As the cost of home computers dropped to less than $1,000 and as Internet service providers shifted to flat-rate pricing, the rate of home PC diffusion and Internet access began to increase. In 1998, more than 42 percent of American homes had at least one personal computer, and 26 percent of American homes were connected to the Internet (NTIA 1999).

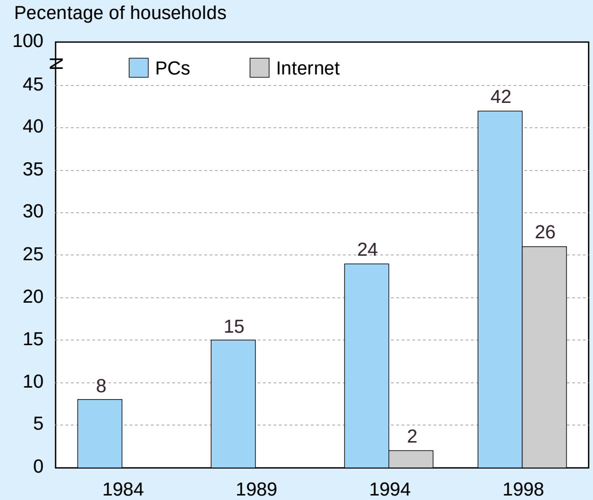
The growing access to home computing has not been evenly distributed, however. People with less than a high school education have less access to computers than people who have completed high school and much less than people who have completed college. (See "Use of Computers and Computer Technology in the United States" in chapter 8, figure 8-19, appendix tables 8-29 and 8-30.) Moreover, the National Telecommunications and Information Administration (NTIA) has repeatedly identified a "digital divide" in the United States, which it defined as a home computing gap between white or affluent Americans and those who are ethnic minorities or poor (NTIA 1995, 1998, 1999). Although disadvantaged groups have substantially increased their home access to computers and the Internet, the gap between these groups and white Americans is growing—at least temporarily.

Trends in PC and Internet Access

Personal computers were commercially introduced in the late 1970s, and home Internet access became widely available to the general public around 1992–93. The earliest reliable data on PCs in the home are from 1984; for Internet access, the earliest data are from 1994.[10] (See figure 9-23.) Rapid growth in home ownership of personal computers has occurred principally since 1994. During the four-year interval from 1994 to 1998, the percentage of households owning a home computer increased by 18 percentage points—double the 9 percentage point increase for the five-year period from 1989 to 1994 and far greater than the 7 percentage point growth from 1984 to 1989. Internet access has expanded phenomenally; the number of households connected to the Internet has grown from 2 percent of all households in 1994 to 26 percent in 1998.

[10]Note that data on Internet access for households do not necessarily reflect constant subscription to the Internet. Households can sign up for the Internet and then drop or even switch Internet service providers (a process known as "churn"). As a consequence, survey data reflect "snapshots" of households connected to the Internet at the point in time at which the survey was administered.

Figure 9-23.
Percentage of U.S. households owning a home computer and percentage of U.S. households with access to the Internet



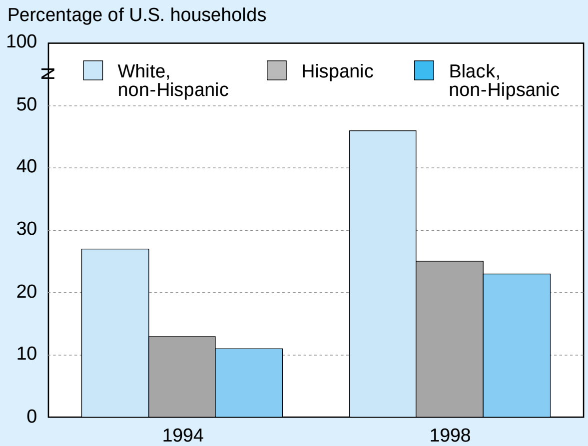
SOURCES: U.S. Census Bureau, except for 1994 data, which is from Clemente (1998).

Science & Engineering Indicators – 2000

Inequities in Access. The recent rapid growth in home adoption of IT masks considerable disparities in access to IT by income levels, ethnic affiliation, and geographic location. Using data from the Current Population Survey conducted by the Census Bureau, the NTIA found that the "digital divide" is worsening among Americans (NTIA 1995, 1998, 1999). From 1994 to 1998, the gap in PC ownership between white and black or Hispanic households widened, as did the gap between rich and poor. Although ownership of home computers and Internet access increased in all income and ethnic categories during these five years, the disparity in ownership has widened. For example, in 1998, 46.6 percent of white Americans owned a home computer, compared to 23.2 percent of black Americans—a gap that increased by nearly 7 percentage points from 1994 (NTIA 1999). (See figure 9-24.) Notably, PC ownership is greatest for households with residents of Asian/Pacific Island heritage—55 percent of such homes own a PC.

Affluence alone does not account for these differences: Within every income category, blacks lag whites substantially in adopting home computers and linking to the Internet, although the gap is not as large at higher income levels. The NTIA reports that "the role of race or ethnic origin is highlighted when looking at similarly situated families. A white, two-parent household earning less than $35,000 is nearly three times as likely to have Internet access as a comparable black household and nearly four times as likely to have Internet access as a Hispanic household in the same income category" (NTIA 1999). Geographic location has an impact on household PC ownership and Internet access beyond that predicted

Figure 9-24.
U.S. household ownership of personal computers, by race/ethnicity: 1994 and 1998



SOURCE: NTIA (1999). *Science & Engineering Indicators – 2000*

by income levels; households in rural areas are less likely to own PCs or be connected to the Internet even when income is held constant in statistical analyses (NTIA 1999). Certain groups thus appear to show consistently low levels of home IT access—particularly households that are low-income; persons who are black, Hispanic, or American Indian; less-educated Americans; single-female headed households; and households located in the South, in rural areas, or in central cities.

Determinants of Home IT Adoption. The research literature on technological diffusion shows that there is a distinctive socioeconomic (income, education, occupation) "early adoption" bias by individuals who are affluent, more highly educated, and from higher-status occupations compared to society as a whole.[11] This pattern holds across all kinds of household products, technologies, and innovations, and personal computers and Internet access are no exception.

Research conducted in the 1980s on home PC diffusion found that income and other socioeconomic factors were strong predictors of early PC adoption (Dickerson and Gentry 1983, McQuarrie 1989, Riccobono 1986); in a major review of the literature from 1980–87 on home IT diffusion and impacts, Dutton, Rogers, and Jun (1987) found that level of formal education was the "single variable most consistently associated with the adoption of computing." Research on the new wave of Internet access confirms the same trend in early PC adoption. The NTIA (1995, 1998, 1999) studies discussed above, as well as Clemente's (1998) findings on Internet households, substantiate the significant influence of income, education, and occupation on home Internet use.

Demographic variables do appear to play a role in home IT adoption behaviors. For example, Hoffman and Novak (1998) found complex relationships among home IT access, race, income, and levels of education. In their study, gaps in home IT access emerged for which neither level of income nor education could account. Hoffman and Novak found that differences in levels of home computer ownership between blacks and whites were statistically significant after controlling for level of education. In addition, Hoffman and Novak found that income could not account for extreme disparities between white and black students with respect to computer ownership: 73 percent of white high school and college students owned a home computer, whereas 33 percent of black students owned a home computer. The NTIA studies also identify persistent differences between whites, blacks, and Hispanics that level of income and education cannot explain.

Research suggests that a few other factors are important influences on IT adoption dynamics. Family structure (marital status of head of household, presence of children in the household, age of the head of household), for example, emerged in several studies as a differentiating factor for home PC and/or Internet access (Caron, Giroux, and Douzou 1989; Clemente 1998; Dutton, Rogers, and Jun 1987; NTIA 1998). In general, families with children and married parents are more likely to have personal computers or link to the Internet than single people, couples without children, single heads of household, or households headed by very young adults. (Note that income could be an intervening factor for these latter two family structures.) In addition, individuals with a positive attitude toward technology or computers are more inclined to adopt personal computers (Dickerson and Gentry 1983; Dutton, Rogers, and Jun 1987).

Patterns of Home IT Use

Research and data on patterns of IT usage fall into two distinct categories: research conducted in the mid-1980s on the use of home computers and research conducted in the mid-1990s on Internet use. Thus, there is a substantial gap in our understanding of how computers are used in the home. Not only do the studies on PCs essentially reflect early users—a group of people who are known to be atypical of the general population—but they tend to be studies that, because of their research design, cannot be generalized to the overall population. In addition, the software and user interfaces that we have today were designed primarily by and for white men, leading to more subtle psycho-cultural influences on adoption patterns (CSTB 1997). As a consequence, the findings for PC use should be regarded as suggestive (certainly not definitive): They identify areas of potential research interest and analytical need.

Home Use of PCs. Early adopters of home computers did not necessarily use their machines intensively. For example, Riccobono (1986) found that in a typical week, 40 percent of adults did not use their computer at all. In general, many households found that they were using the PC less than expected, and in Riccobono's national study, 43 percent of adult computer owners indicated that they used their computers much less than they expected at the time of purchase. These find-

[11] "Early adopters" are individuals who purchase and use new technologies when they are introduced to the marketplace. See Dickerson and Gentry (1983) and McQuarrie (1989) for treatments of the literature on early adopter patterns in households.

ings are consistent with other "underutilization" findings reported in Caron, Giroux, and Douzou (1989); Dutton, Rogers, and Jun (1987); and Giacquinta, Bauer, and Levin (1993).

These patterns of use were variable across family members, however. In the Riccobono study, only 16–20 percent of children in the home ages 6–17 did not use the computer at all in a typical week, compared to 40 percent of the adults. Although 45 percent of the parents were non-users in the Giacquinta, Bauer, and Levin study, only 16 percent of the children were non-users. Fathers tended to dominate use of the computer in the home (Caron, Giroux, and Douzou 1989; Giacquinta, Bauer, and Levin 1993), and females tended to represent a higher proportion of non-users across all age groups (Giacquinta, Bauer, and Levin 1993, Riccobono 1986).

Evidence regarding the dominant content of PC use (for example, word processing, education, games, and so on) is mixed, and the research cannot be systematically summarized because of limited data, vastly different research designs, and different ways of presenting questions to survey respondents. The one theme that consistently emerges is the major role of education in early-adopter PC use; the importance of educational uses of the computer tends to be cited more often and in higher proportions by most studies than any other type of application (Dutton, Rogers, and Jun 1987, OECD 1998). Other salient uses appeared to be games, word processing, and work-related tasks, as well as programming and learning about the computer itself (Caron, Giroux, and Douzou 1989; Dutton, Rogers, and Jun 1987; Giacquinta, Bauer, and Levin 1993; OECD 1998; Riccobono 1985).

Home Use of the Internet. E-mail and World Wide Web (WWW) activity dominate home Internet use; in general, e-mail appears to be the more important activity. Kraut, Mukhopadhyay, et al. (1998) find from computer records that people use e-mail more frequently than the WWW and will use e-mail first in online sessions that include both e-mail and WWW activity. Indeed, people who used e-mail more than the WWW were more likely to continue using the Internet over the course of a year than people making greater use of the Web. Census data indicate that e-mail is used overwhelmingly to communicate with family and friends: More than 90 percent of all users report using e-mail at home for this type of communication, compared to only 33 percent (or less) who report using e-mail for work, hobbies, or educational activities (NTIA 1999).

Use of the Web is both idiosyncratic and generalizeable. For example, Kraut et al. (1996) find that the Web sites visited by family members in their study were unique to the individual. Of the roughly 10,000 unique addresses visited during the study, 55 percent were accessed by only one person, and less than 2 percent were visited by 20 percent or more of the individuals in the sample (these sites tended to be search engines and Web portals).

Usage is nonetheless patterned by broad categories. For example, in terms of general information searches, the American Internet User Survey reveals that health and medicine are the most popular Internet subjects. Thirty-six percent of all users and 47 percent of women report exploring this subject; other major areas of interest include entertainment, music, parenting/children, and lifestyles subjects.[12] NTIA (1999) finds distinctive patterns of Internet use in terms of the purpose for using the Internet at home. In general, individuals with higher income and higher education levels are far more likely to use the Internet for work-related activity, whereas minorities and unemployed individuals are enthusiastic users of the Internet for employment searches and taking educational courses.

Research and Findings on Effects of IT on the Home

Three categories of impact research are addressed here: time displacement studies, the impacts of teleworking on the home, and psychological well-being. The limited research on the impacts of IT shows this technology to be a bit of a mixed blessing: Although IT has the potential to improve the quality of life of the home and the individuals within it, IT also has the potential to be abused or lead to harmful consequences.

Time Displacement Studies. Time displacement studies assess the degree to which the introduction of a new technology in a household affects patterns of time use and allocation. Such studies have been carried out with respect to vacuum cleaners, automobiles, televisions, and microwave ovens, among other technologies. Three time displacement studies have been conducted with respect to home computing. Two focus on the impacts of home computing and the Internet on use of traditional news media (newspapers, TV, radio, books, and magazines); the other explores how individuals reallocate their time once home computers are brought into the household.

Robinson, Barth, and Kohut (1997) analyzed data from the Pew Research Center for the People and the Press on IT in the home. Curious about whether use of the Internet and home computers displaces use of traditional news media, the authors analyzed 1994 and 1995 survey data that reflect when and how often individuals use different kinds of media. Although they found a variety of correlations, few were statistically significant, of meaningful magnitude, or represented a clear pattern that could not be accounted for by socioeconomic factors. In general, however, the authors found that IT use in the home was associated with an increased use of traditional news media, not a decrease. Although they conclude that IT may therefore be media enhancing, home IT users also may be generally more "news seeking" than non-IT users.

Clemente (1998) analyzed data from the American Internet User Survey conducted by Cyber Dialogue and found patterns of media displacement that tend to support the Robinson, Barth, and Kohut findings. Clemente found that about one-third of all Internet user households reported that they watched less TV, although this displacement tended to be slightly higher for recent adopters than those who had been using the Internet

[12]Data from the American Internet User Survey (<<http://www.cyberdialogue.com/free_data/index.html>>), accessed August 19, 1999.

for a year or more. The number of households that had been using the Internet for more than one year that reported declines in reading of newspapers, books, or magazines and listening to the radio ranged from 10 to 13 percent.

Vitalari, Venkatesh, and Gronhaug (1985) cast a broader eye on the time allocation impacts of home computing. In a study of 282 members of computer clubs in Orange County, California, the authors assessed the impact of computing on 10 household activities: watching TV, reading, leisure time spent with family, leisure time spent with friends, outdoor recreation, sports, hobbies, sleeping, time spent alone, and studying/doing homework. Notably, 96 percent of the respondents were men; this gender bias, as well as other factors (the majority of respondents had previous experience with computers and worked in technical professions) make this a particularly nonrepresentative group of respondents.[13] Nonetheless, the authors detected major time reallocation patterns; major shifts (e.g., more than 20 percent of the respondents reported the change) were detected with respect to decreased television watching, outdoor recreation, hobbies and sleeping, and major increases in time spent alone and studying were observed. (Note that these latter two activities are not mutually exclusive.) The greatest shifts in time allocation patterns were reported in families with children—suggesting that such households are particularly sensitive to the introduction and presence of a computer.

IT, Work, and the Home. Teleworking has long been hailed as one of the major social benefits of IT. By enabling individuals to stay home and work—whether by telecommuting to a parent office or establishing a home-based business—the relocation of work to the home is believed to offer multiple advantages to individuals and families. Flexible work hours, lower household costs, less stress from family—work conflicts, reduced commuting times, and so on are believed to be important payoffs to computer-based work at home.

The vast majority of research on teleworking addresses the economic benefits of these arrangements to parent companies. Traditional research on the impacts of telework focuses on such factors such as productivity, job satisfaction, work attitudes, job stress, overwork, and employee turnover. Little research has been conducted on teleworking in which the impact on home and family life are the focus. Habib and Cornford (1996) reviewed the research related to telework impacts on the home and identified key areas of concern: the effect on rules, norms, and roles in the household; the blurring of spatial boundaries between home and office; and the disruption of time patterns in family routines. Gurstein's (1991) research on 45 home workers echoes these concerns. Her research indicates that IT home workers express guilt over neglecting their families, discomfort with the loss of their home as a "refuge" from work, and a sense of isolation and being devalued by their office colleagues. Gurstein wonders exactly what flexibility advantages are created by telework and concludes that home-based computer work "results in role conflicts, inadequate workspaces, the blurring of the work/leisure time division, and the tendency for 'overwork' to occur" (Gurstein 1991, 177).

In contrast, Riley and McCloskey (1996) found that limited use of teleworking arrangements may have positive home impacts. Reporting on a pilot program in which GTE Corporation allowed managerial employees to work at home one day a week for six months, the authors found that "of the 120 participants in the telecommuting pilot study, 75 percent reported increased feelings of satisfaction with their home life, [and] 44 percent reported having more quality time with the family" (Riley and McCloskey 1996, 87).

[13]In addition, because this study was most likely conducted in 1984, respondents are also "early adopters" of home computers. As others have shown (e.g., Dutton, Rogers, and Jun 1987), early adopters of home computers are atypical of the general population in a variety of ways.

IT and Disabilities

Information technologies have the potential to improve the lives of people with disabilities. IT can make work from home more viable for people with limited mobility, turn written material into spoken language for visually impaired people, and turn speech into text for hearing-impaired people.

Information technologies do not automatically provide benefits to the disabled, however. Unless they are designed carefully, they can create new barriers. Web sites, for example, frequently convey information in a visual form that is inaccessible for people who are visually impaired.

The World Wide Web Consortium, a standards-setting organization for the World Wide Web, has developed guidelines to make Web sites more accessible (<<http://www.w3.org/TR/WAI-WEBCONTENT/>>). Among the guidelines are the following:

- ♦ There should be text equivalents for all nontext elements, including images, animations, audio, and video.
- ♦ There should be text summaries of graphs and charts.
- ♦ All information conveyed with color should also be available without color.
- ♦ The clearest and simplest language appropriate for a site's content should be used.

The Center for Applied Special Technology (<<http://www.cast.org>>) provides a free Web-based tool to analyze Web pages for their degree of accessibility to people with disabilities. Within the U.S. government, the Center for IT Accommodation (CITA; <<http://www.itpolicy.gsa.gov/cita/>>) in the General Services Administration's Office of Procurement Policy works to improve the accessibility of information technology.

These telework studies generally predate widespread access to the World Wide Web and major changes in distributed work arrangements in the private sector. As a consequence, they may not reflect the variety of household impacts that come from less insulated and "closed" work systems. Nonetheless, these studies are suggestive of a common theme in the theoretical and philosophical literature on IT—namely, the omnipresent duality of IT impacts. On one hand, teleworking can enhance people's ability to better balance work and family needs and reduce personal stress. On the other hand, home-based IT work can disrupt crucial family dynamics (roles, interpersonal relationships, and the sense of home as sanctuary) and create psychological isolation and low self-esteem. The extremely limited research described here suggests that there may be threshold effects associated with telework: The degree and intensity of telework's presence in the home may be damaging rather than telework per se.

Psychological Well-Being. As with so many other potential impacts of IT in the home, the influence of computing on the psychological well-being of individuals can be beneficial or harmful. Greater connectedness to a community, ease of communication with family and friends, and improved access to information can enhance self worth, feelings of satisfaction, a sense of community and kinship, and personal empowerment. Scholars express equal concern, however, for the dark side of computing: isolation; growing social insularity; and increasingly, "Internet addiction." A body of psycho-behavioral work exists with respect to computer-human interactions and computer-mediated communication; three empirical studies stand out, however, with respect to the psycho-behavioral impacts of Internet use. These studies relate to Internet addiction, social integration, and loneliness and depression.

Although the existence of Internet addiction as a clinical disorder remains in dispute, some professionals unequivocally assert that it is a real phenomenon.[14] Egger and Rauterberg (1996) explored whether heavy use of the Internet reflects addictive behavior; data were obtained from an online survey posted and advertised on the World Wide Web. Roughly 450 valid survey responses were received, largely from Swiss and American respondents.[15] Although the findings of the survey cannot be generalized outside the sample, the key findings are suggestive for future research. First, 10 percent of respondents perceived themselves as addicted to or dependent on the Internet, and objective measures of addiction, on the whole, were statistically significant for this group. Second, this small group of "Internet addicts" represented all walks of life. There were no statistically significant demographic differences between people who were considered Internet addicts and those who were not—this group was not differentiable by gender, age, nationality, or living situation.

Concerns that Internet users may be socially withdrawn from their communities are not substantiated in research reported by Katz and Aspden (1997). They found that after controlling for demographic differences between groups (age, gender, education, race, and income), there were no statistically significant differences in the degree to which Internet users were members of religious, leisure, or community organizations compared to non-users. In addition, Katz and Aspden found that the vast majority of Internet users (whether recent or long-term) reported no change in the amount of time spent with family and friends on the phone or through face-to-face contact. Interestingly, the data indicate that long-term Internet users belong to more community organizations than any other group (non-users, former users, and so forth).

In contrast, Kraut, Lundmark, et al. (1998) found evidence that greater use of the Internet was associated not only with increased social disconnectedness but with loneliness and depression as well. Using data from the HomeNet study, the authors found that greater use of the Internet was associated with "small but statistically significant declines" in social integration as reflected by family communication and the size of the individual's social network, self-reported loneliness, and increased depression. These correlations held even after the authors controlled for initial states of loneliness, social involvement, Internet use, depression, stress, and so forth. Although the authors' claim that their methods and findings indicate a causal relationship between increased Internet usage, declining social involvement, and worsening psychological states is an overstatement, the findings nonetheless show important statistical associations.[16]

IT at Home: Summary

Twenty years after the advent of the personal computer, we have a relatively clear picture of who has access to home computers and, more recently, the Internet. Patterns of IT diffusion and adoption clearly suggest that IT is still a resource acquired to a greater extent by more affluent and well-educated Americans. Although PCs have been diffusing rapidly in recent years, they have yet to make substantial inroads into poor and minority households, and research on PC and Internet adoption behaviors indicates that socioeconomic and demographic factors continue to be the primary predictors of home IT access. Very simply, income allows families to hurdle affordability barriers to adoption, and well-educated individuals are more likely to be aware of and appreciate the ways IT can be used in the home.

The picture is less clear with respect to usage patterns. The early adoption research suggests that the primary uses of home computing are for education, play, work, and basic word processing; findings generally suggest that children tend to use home PCs more often and for longer periods than adults. Sizeable proportions of early adopters found that they used the computer less than they initially expected.

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[14]See, for example, Kimberly S. Young, *Caught in the Net* (NY: John Wiley and Sons, 1998).

[15]The authors were from Switzerland, so most of the respondents were Swiss. The survey was posted in English and German, however.

[16]The models do not account for environmental conditions known to trigger social withdrawal and depression (such as loss of a job or marital conflict). Thus, they do not allow for intervening environmental variables or the possibility that greater Internet use could be a consequence of depression, loneliness, and social withdrawal caused by other factors.

Recent research on Internet use reinforces some of the impressions generated by the early computing studies: Children and male teenagers still tend to be the heaviest users of IT. The Internet has made a new form of interpersonal communication available to households, and several analyses suggest that e-mail and personal communication drive Internet use by individuals and households. Specific informational content derived from the World Wide Web is unique to each individual's interests and needs, although broad patterns of information use are emerging. Americans most often seek information related to health and leisure; affluent and educated individuals also use the Internet for work, whereas socioeconomically disadvantaged groups use the Internet to seek jobs and to take classes.

What we do not know about impacts is substantial. How do families and individuals use information gained from the World Wide Web, and with what consequence? What are the outcomes of the growing role of e-mail in some families' lives? Are families with e-mail any better off than families without e-mail? How does the presence of home computing affect family dynamics and relationships? Does it diminish or enhance quality of life, and under what circumstances? Are there pathologies associated with extensive Internet use? How does computer-based work at home affect the nature of the home itself?

Least understood is whether the socioeconomic inequities that exist in access to home information technologies matter, and how. The implicit assumption is that the absence of IT in the home perpetuates social and economic disadvantages. Childers (1975) creates a vivid portrait of how minorities, the underclass, and other groups in the United States tend to have fewer lines of access to information and less effective information networks than the rest of society. On the other hand, if the effects of computers on the home are mixed, the lack of home computers may not be as critical.

Information Technology, Government, and Citizens

Like businesses, government agencies have used IT in management information systems and in research for decades. With the advent of the Internet and especially the World Wide Web, however, IT has become a major means of communicating with citizens and stakeholders.

IT influences government in a variety of ways. The Internet is a very effective way to disseminate government-related information. Government agencies are placing information about their policies and programs, as well as information that they have developed or supported, on the Web. Examples of U.S. government information resources include STAT-USA (<<http://www.stat-usa.gov>>)—a service of the U.S. Department of Commerce that provides business, economic and trade related Federal Government information—and NSF's science statistics (<<http://www.nsf.gov/sbe/srs/stats.htm>>), including this volume. The National Technical Information Service (NTIS), which has been the distribution channel for government-sponsored technical reports, recently decided to close because agencies are offering their publications directly to the public over the Internet (for no charge). States and local governments are also using the Web to make information readily available to the public.

The Internet is also affecting political processes in the U.S. and around the world. Political candidates are establishing Web sites to communicate with voters, solicit funds, and organize volunteers. Interest groups are using e-mail and Web sites to organize and express their views. In some cases, groups that would be very difficult to organize through traditional means—such as scientists or engineers in different parts of the country—can be mobilized through e-mail to express their views to the Congress on a timely issue. Other groups are experimenting with Internet voting. For example, the U.S. military is exploring using the Internet to provide a new mode of absentee voting for its overseas personnel.

Overseas, the Internet is providing a way around government controls on information. If a country allows its citizens to have access to the Internet, it is very difficult to prevent them from using it to gain access to information. For example, although China controls Internet service providers and blocks access to many Web sites, overseas Chinese send news via e-mail to large numbers of e-mail addresses, obtained from public lists, in China (Plafker 1998). The people who receive the e-mail can honestly tell authorities that they did not request the information.

As in the United States, governments around the world are using the World Wide Web to communicate with their constituencies. The Cyberspace Policy Research Group at the University of Arizona analyzes worldwide government use of the Web. Group members scan the Web for new agency sites, record the URLs, and analyze Web operations according to indices of transparency, interactivity, and openness. (See figure 9-25.)

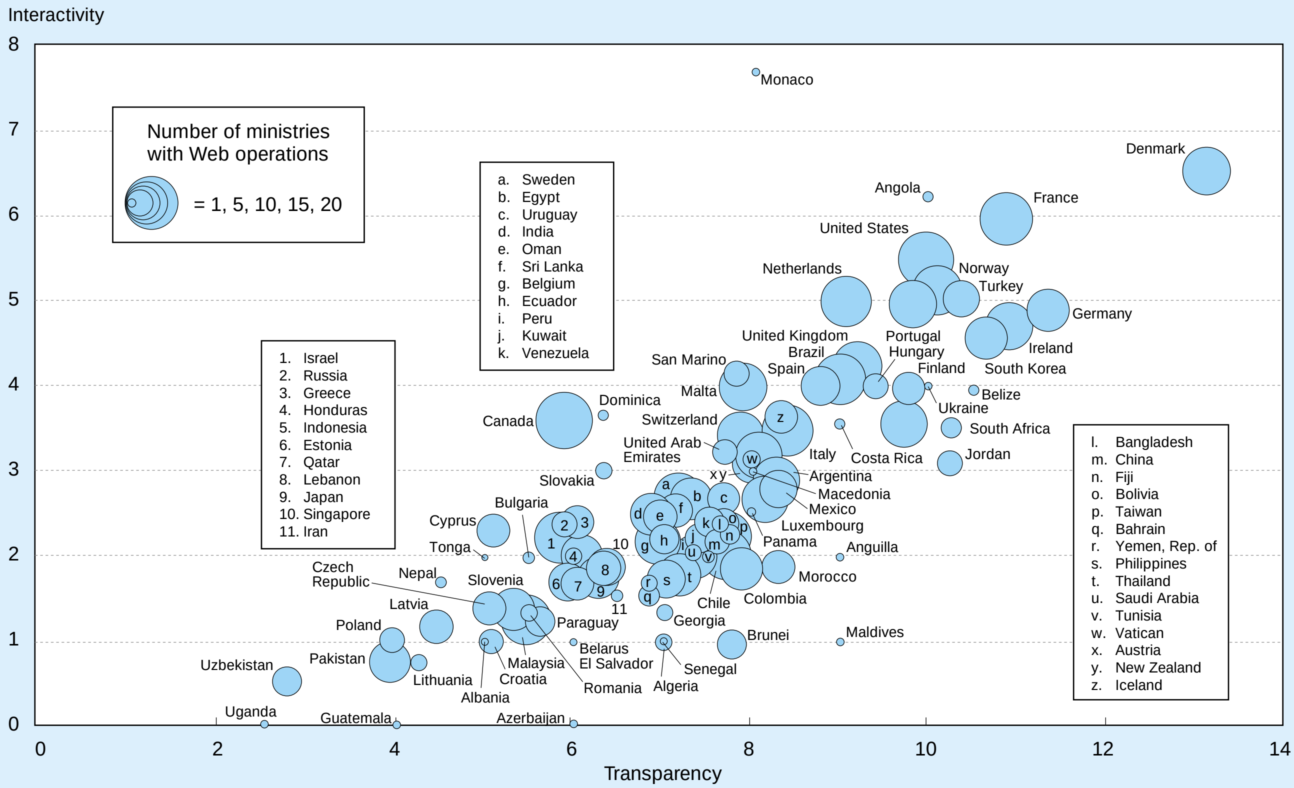
The transparency index measures the information an agency provides about itself and is based on measures of:

- ♦ how involved the agency is with the site;
- ♦ how easily the Web site visitor can contact people in the organization;
- ♦ how well information is provided about an organization's operations and relationships with other organizations;
- ♦ the extent to which the Web site helps citizens comply with regulations or take advantage of government programs, such as by making forms available; and
- ♦ how current an agency's information is.

The interactivity index measures the convenience with which information can be accessed. If information is theoretically available but practically difficult to obtain, the organization scores poorly on interactivity.

The size of each bubble in figure 9-25 indicates the number of top-level government agencies with Web sites for that country. The vertical axis shows the country's rating on interactivity, and the horizontal axis shows its rating on transparency. Countries in the upper right quadrants can be consid-

Figure 9-25.
Openness and its components: transparency, interactivity, and number of ministries



See appendix table 9-9. *Science & Engineering Indicators – 2000*

ered to use the Web to enhance the openness of government to a greater extent than countries in the lower left quadrant. A large number of national governments use the Web extensively. Almost 40 countries had Web sites for 70 percent or more of their agencies in 1998, and 17 countries had Web sites for all of their top-level agencies. (See appendix table 9-9.) There is also substantial variation in the measured transparency and interactivity of the countries, suggesting that countries vary in the extent to which they are currently taking advantage of the Web to interact with their citizens.

Conclusion

IT is having substantial effects on many domains of society, including the economy, education, research, and the home. In most areas, however, the effects of IT—and the choices that can be made to influence the effects—are not well understood. Moreover, significant new technologies are changing the nature of the effects as they are being researched. There is a large agenda for future research.

NSF sponsored a National Research Council (NRC) study of research needed on the economic and social effects of IT (CSTB 1998). Although the NRC panel did not attempt to provide a comprehensive research agenda, it highlighted an illustrative set of promising areas for research:

- **Interdisciplinary studies of information indicators.** Interdisciplinary study could help to identify and define a set of broadly accepted measures of access to, and the use and effect of, information and IT. (See sidebar, "Potential Information Technology Indices.")
- **Effects of IT on labor market structure.** To facilitate informed decisions on issues such as how to respond to increasing wage inequality, it is important to understand how and to what extent the use of computers might affect wage distribution.
- **IT, productivity, and its relationship to work practices and organizational structures.** Much evidence suggests that IT's effect on productivity depends on how it is used in organizations. Compilation of work that has already been done in this area is needed. Continued research also could illuminate how to better quantify the economic inputs and outputs associated with use of computers.
- **Intellectual property issues.** Policymakers considering revisions to intellectual property law or international agreements, as well as firms evaluating possible approaches to protecting intellectual property, would benefit from continued theoretical and empirical research.

- **Social issues addressed at the protocol level.** Widespread use of the Internet has far-reaching effects on intellectual property rights, privacy protection, and data filtering. Exploring how these concerns might be addressed at the protocol level—through policies, rules, and conventions for the exchange and use of information—could be a promising approach to addressing issues arising from the use of new computer and communications technology. Examples include the Platform for Internet Content Selection (PICS)—which implements a set of protocols for rating Web sites—and P3P, a project for specifying privacy practices.

The NRC panel also identified ways to improve the data needed to study the economic and social effects of IT, such as making data related to the social and economic effects of computing and communications available to the research community through a clearinghouse; exploring ways for researchers to obtain access to private-sector data; and establishing stronger ties with industry associations to facilitate collaborative research.

Potential Information Technology Indices

Interconnectivity index. This index would provide a measure of the facility of electronic communication and an evaluation of the development of this dimension of the information infrastructure.

Information quality of life index. Similar to an index produced by OECD, this index would attempt to evaluate the qualitative levels of communication available to individuals.

Leading information indicators. This index would attempt to predict the growth of the information infrastructure.

Home media index. This index of the state of penetration of communications technologies in the home might qualify as a leading index of the potential for future consumption of information.

Marginalization index. This index would measure the extent to which specific populations are excluded from participation in the information infrastructure.

SOURCE: CSTB (1998).

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